CHROMOSPHERIC AND TRANSITION REGION DYNAMICS – REASONS AND CONSEQUENCES OF THE SHORT PERIOD INSTRUMENTAL PERIODICITIES of SUMER/SOHO

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ABSTRACT

The observational method can cause periodicities in the spectral line intensities and velocities, determined with the SUMER spectrometer onboard SOHO. On long-term measurements of O I, C II and O VI lines, originating in the upper solar atmosphere, it is shown that the reason of these periodicities was the spectrometer slit position stepping of the solar rotation compensation. The standard rotation compensation procedure, performed on-line by the instrument, was selected for these long-term observations. The residual periodical motion of the slit position on the solar disk was taking place and it produced the regular variations of the measured line intensities and velocities. Unfortunately, these regular variations significantly enhanced amplitudes in the frequency range where the real solar oscillations were already determined!

Consequences of this effect for SUMER measurements of the chromospheric and transition region dynamics are discussed. Procedures how to exclude the effect from the data post-facto as well as how to modify the future SUMER oscillations measurements in order to avoid the effect are proposed.

Key words: Sun: transition region – Sun : chromosphere – Sun: dynamics – instrumentation: SUMER.

1. INTRODUCTION

One of the principal scientific objectives of the SOHO mission is the study of heating mechanisms of the upper solar atmosphere including the transition region and the corona. Some of the proposed mechanisms are based on the wave transport of the energy from the convective layers up to the corona, where it should dissipate to heat the plasma, by persistent waves of different types. Some of such waves should be detected by observations when the actual properties of the particular waves 'fit' with the resolutions and sensitivity of the used instruments.

Several SUMER observations of the oscillations, especially in the chromosphere and the transition region, have been performed up to now. The first results have already been published from measurements of the emission lines and continua, taken in the quiet solar atmosphere (Balthasar et al., 1997, Betta et al., 1997, Carlsson et al., 1997, Curdt et al., 1997a, Curdt and Heinzel, 1998, Heinzel and Curdt, 1999, Gouttebroze et al., 1999, Judge et al., 1997, Kučera et al., 1998, Steffens et al., 1997a, 1997b, 1997c, Wikstøl et al., 1997).

In these studies considerations of the solar rotation induced variation of the spectrograph slit position relatively to the solar disk are of major importance. The intrinsic rotation compensation schemes of SUMER (Wilhelm et al., 1995), used in several of these studies, perform 0.76" steps at a rate required by the solar rotation. Unfortunately, this leads to a step rate of approximatively 1 step every 300 s at the disk center, a frequency of which could interfere with the solar oscillations of interest, unless the command code is structured approximatively. The aim of this contribution is to document this effect on the intensity and velocity oscillations power spectra and to propose possible ways of how to overcome this interference problem to some extend.

2. INSTRUMENT

The SUMER spectrometer was prepared for the SOHO mission in order to investigate processes over the temperature range from 10^4 to 2×10^6 K with the ability to measure the above mentioned waves running from the chromosphere through the transition region to the inner corona. High spatial, spectral and temporal resolutions of SUMER in the UV range of the solar spectrum made the instrument very suitable for the determination of waves in the upper solar atmosphere. SUMER is a high-resolution normal-incidence spectrometer, described in detail by Wilhelm et al. (1995). Summaries of its in-flight performance were presented in papers of Wilhelm et al. (1997), Lemaire et al. (1997) and Wilhelm (1997). The high practical spectral resolution was confirmed by the in-flight measurements of the narrowest lines with the FWHM of only 86 mÅ as like as the clear separation of the H I Ly line series up to member 19 and 20 (Wilhelm et al., 1997) The practical spatial resolution, derived from the faintest solar features, was estimated to be 2" along the slit and 1.2" across the slit using the slit position step of 0.38" (Lemaire et al., 1997). The typical exposure times of the order of 10 s are required for the sufficient S/N ratio which is inevitable for the appropriate profile determination of the most pronounced spectral lines originating in the chromosphere and the transition region. SUMER was prepared with the intrinsic possibility to perform the automatic compensation of its slit position in order to follow the rotational motion of the selected target.

3. DATA

The instrumental effect was analyzed in the SUMER data set acquired on 7 Sept 1996 ($7^h53^m45^s$ – $11^h47^m45^s$). The set is a long time series of 929 spectral images around the following emission lines : O I 1027.43 Å, C II 1037.02 Å and O VI 1037.61 Å. All spectral images were taken simultaneously with the integration time of 15 s and they were telemetry limited. Data were acquired on the central part of the detector A. The entrance 1"×120" slit of the spectrometer was oriented in the NS direction. Its position in the EW direction was shifted 30 times in order to follow the rotational motion of the selected target on the solar disk in the range from 4.5" to 39.88". The standard compensation scheme was used for this purpose. Each step was performed after a packet of 31 spectral image exposures, corresponding to 465 s. Information on the actual slit position was extracted from the header of SUMER data files for each spectral image. The quiet Sun area very near the disk center was selected including two supergranular boundaries crossing the slit. More details on the used data can be found in papers of Curdt et al. (1997a, 1997b).

4. REDUCTION

The basic data reduction was performed with help of the standard SUMER reduction procedures[1]. All data have been decompressed according to the compression algorithm applied onboard. Relative sensitivity of the detector pixels was taken into account using the deep flat-field data obtained on 11 Sept 1996. Aberrations of the spectral images were corrected using the available destretching algorithm with its auxiliary data. A slight residual curvature of the spectral lines still exists after this correction, but it is stable during the run. It does not affect the results and conclusions of this paper. Data were also converted to physical units using the available radiometric calibration procedure. In order to decrease the random noise the spatial binning of 2 pixels (2.02") was applied along the slit length. Due to the internal vignetting of the slit images the spatial dimension of the final spectral images was truncated to 43 binned pixels (86.86").

[1]These can be found for example at http://sohowww.nascom.nasa.gov/descriptions/experiments/sumer/sch-cookbook.html

Finally each spectral profile in the data sets was fitted using a simple Gaussian profile and a linear background. The CFIT algorithm of S. Haughan was used for the fitting calculations[2]. The profiles of C II and O VI lines were fitted together. Relative weightening of the data was applied in each spectral profile. Data were weighted according to the reciprocal square of their relative intensity. Few fitting results were omitted from the investigation due to very large χ^2 values. The velocities were determined from the line wavelength shifts subtracting the instrumental overall spectral image drift caused by the 'thermoelastic oscillations' of the spectrometer's mechanical structure (Dammasch et al. 1999, Curdt et al., 1997a, 1999). Then the mean wavelength of all profiles was set as the zero reference velocity for each line.

5. SUMER ROTATION COMPENSATION PERIODICITIES

In the research of the plasma oscillations it is of a particular importance to observe an identical area of the Sun for the whole time of the measurements. Otherwise the actual effect of plasma oscillations on the spectral line profiles would be mixed with other changes caused just by observations of different plasma volumes above the different places of the solar surface. Therefore the rotation compensation was included in our SUMER observations.

The time-slice maps of the emission line intensities and velocities made from these observations have been already published by Curdt et al. (1997a) and Kučera et al. (1998). These maps display unexpected sharp changes of the line parameters covering a significant part of the slit length. We have made a comparison of the line characteristics with the available information on the EW position of the slit exactly in the time when the exposures of the spectral images were taken (SUMER Y coordinate of the file header). The aim was to check the possible effect of the SUMER rotation compensation used for this observation. Relevant plots are displayed in Fig.1 and Fig.2. The temporal behaviour of the investigated line intensities and line wavelength shifts (velocities) are plotted here for the whole run for the particular part of the solar surface (6.06" along the slit) covered by the supergranulation boundary (Fig.1). In order to take away the actual rotation of the followed target from the information on the SUMER slit position the temporal linear trend has already been subtracted from the SUMER coordinate Y (Fig.2). Therefore the residual sharp 'sawtooth' changes of the displayed residual slit motions correspond to the shift of the slit from previous position to a new position after each 465 s. Two different steps of the slit (0.76" and 1.42") were performed as a consequence of the specific SCL code. For most of these line changes an exact temporal coincidence with the steps of the rotation compensation was found. At the time of some of these jumps the significant changes of intensities and velocities of all three lines are evident (e.g., just before 11 h). The coincidence is more pronounced in the C II and O VI lines. On the other hand some of the slit steps do not reflect any change of the line intensities

[2]CFIT description is available at http://orpheus.nascom.nasa.gov/cds/home/swnotes/

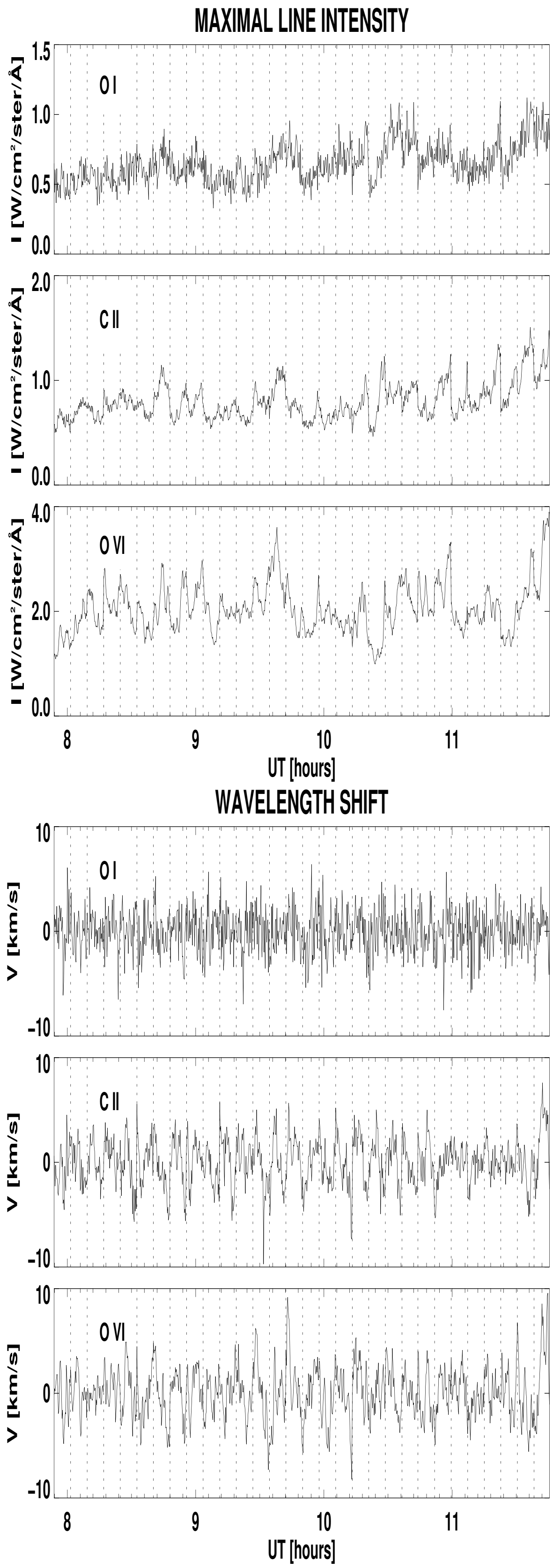

Figure 1. The plots of the O I, C II and O VI maximal line intensities (upper three panels) and plots of the velocities of these lines (bottom three panels) on the supergranular boundary. The vertical dotted lines mark the moments of the performed slit steps (Fig.2).

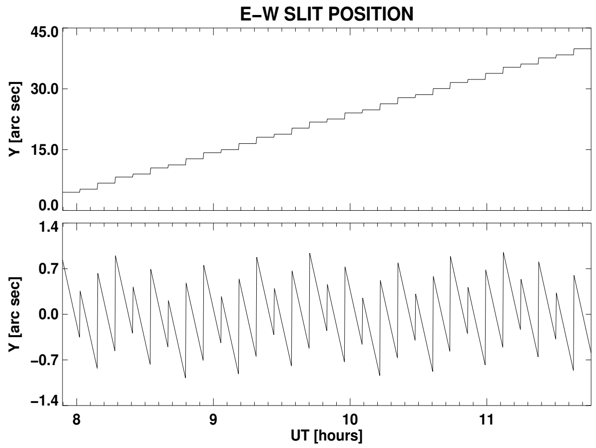

Figure 2. The plot of the SUMER coordinate Y, giving the actual slit position in the moment of the exposure (upper panel). The residual slit motion displays the relative slit position to the smooth rotational motion of the solar target (bottom panel).

and/or velocities in all measured lines (e.g., 11.7 h). The significant artificial intensity (velocity) changes appeared only when slit stepped between two areas which had rather high differences in the line intensity (velocity). No changes of the intensity (velocity) was obtained if the steps were made between similar areas concerning their intensity (velocity).

In order to check the significance of the slit movements for the whole data set the correlations between the line intensities (velocities) and the residual slit motion were calculated for the supergranulation boundary (Fig.3). The behaviour of the correlations confirm the general relation of the line changes with the slit residual motion. Although the correlation coefficient level is not high, the behaviour of the correlation is periodic with a period about 8 minutes which is comparable to the time interval without any motion of the slit (Fig.2, upper panel). Two possible reasons for the low correlation level could be mentioned : 1/ the line intensity (velocity) differences between the last measurement before the slit step and

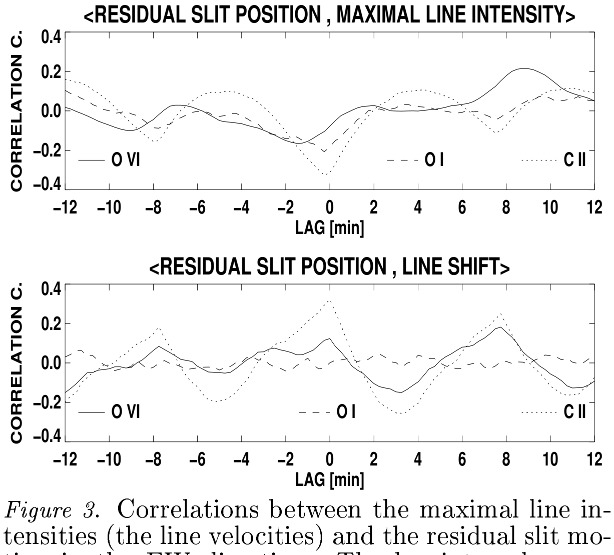

Figure 3. Correlations between the maximal line intensities (the line velocities) and the residual slit motion in the EW direction. The lag interval covers roughly 3 times the time interval between successive slit motions performed during the data acquisition.

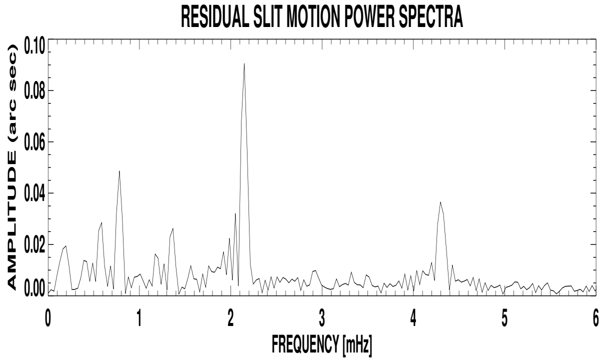

Figure 4. The power spectrum of the residual slit motion (Fig.2, bottom panel) which gives the relative position of the slit to the position of the selected target.

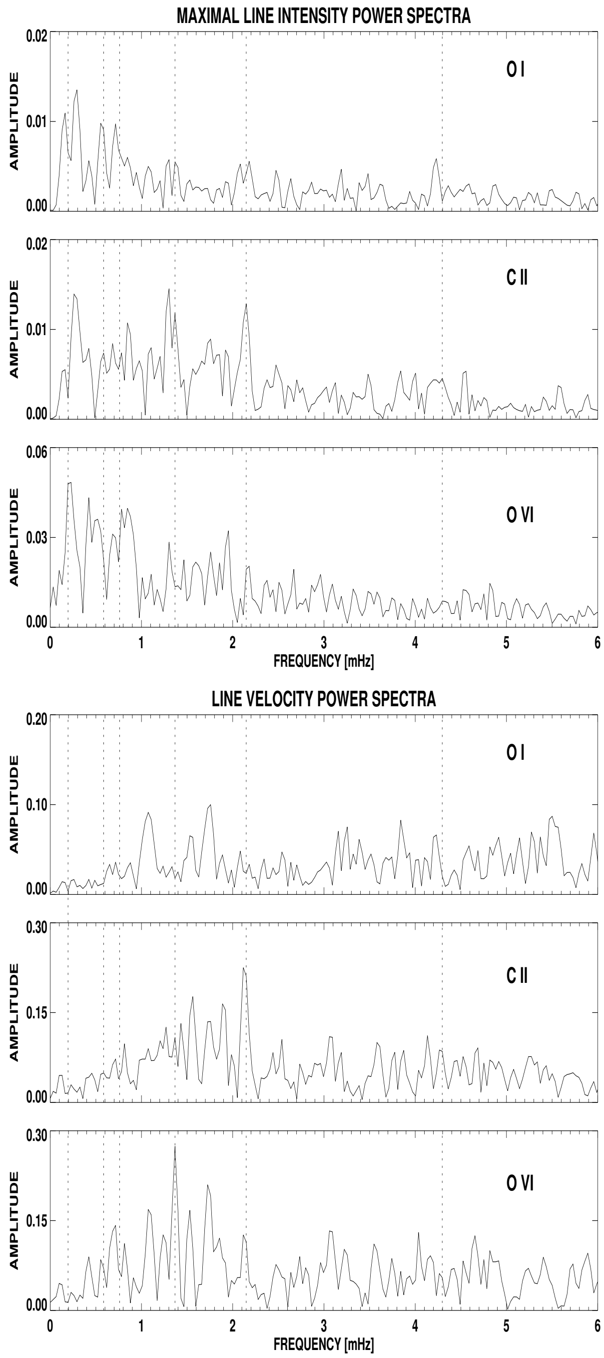

Figure 5. The power spectra of the O I, C II and O VI maximal line intensities and the line velocities. The power spectra were calculated after the subtraction of the data bias calculated by the cubic approximation of the line intensities (velocities), extension of these line intensities (velocities) data sets for 10% and their windowing with a 10% cosine window. The amplitudes are given in $\mathrm{W\,cm^{-2}\,ster^{-1}\,\AA^{-1}}$ and $\mathrm{km\,s^{-1}}$ for the intensity and velocity power spectra respectively. The vertical dotted lines mark in these panels the positions of the most pronounced frequencies in the residual slit motion power spectrum (Fig.4).

the first one after the step do not exist during the whole time of observations; 2/ the intrinsic solar variability of lines masks the influence of the slit steps on the line intensity (velocity) changes as it produces variations of lines not related to the slit steps. Nevertheless the relation between the line characteristics and the residual slit steps enables us to point out that the instrumentally caused *SUMER rotational compensation periodicities (RCPs)* exist when the standard rotational compensation scheme is used onboard. The effect is most evident on the correlations derived for the hotter O VI and C II lines. Contrary to that the O I line (especially in the velocity) shows almost no influence of the performed slit position shifts.

6. POWER SPECTRA

Most of the information on the oscillations of the solar plasma is derived usually from the power spectra of the spectral line velocities or intensities. Therefore we have tried to estimate the effect of the applied standard rotation compensation scheme on the velocity and the intensity power spectra to answer a question whether the SUMER RCPs affect also this most common oscillations diagnostic tool. The power spectrum of the residual slit motion, given in (Fig.4), displays the most prominent peak at 2.15 mHz, corresponding to the time interval between the successive slit steps. The other peaks of the power spectrum (near 4.3, 1.4 and 0.8 mHz) belong to the two-fold of this basic frequency and to the frequencies related to the multiples of the basic time interval of 465 s.

The intensity and velocity power spectra of all three lines (Fig.5) do not contain such prominent peak at 2.15 mHz as the power spectrum of the residual slit motion does. This is especially the case of the O I line intensity power spectrum. On the other hand, both power spectra of C II line clearly present the enhanced amplitudes at the basic and related frequencies of the SUMER rotation compensation periodicities. In the power spectra of the O VI line only some rather pronounced multiple peaks of lower frequencies seem to coincide with the power spectrum of the SUMER rotation compensation periodicities. The amplitudes at the basic frequency of 2.15 mHz are not so significant. The reasons of the relatively lower impact of the RCPs on the presented intensity and velocity power spectra are the same as in the case of the presented correlations between the residual slit motion and the maximal line intensities and the line velocities (Sect. 5). Nevertheless, it can be concluded that at least the presented power spectra of the C II and O VI lines, originating in the transition region, contain also the power coming from the RCPs.

7. DISCUSSION

The high quality of the SUMER telescope was documented by laboratory tests (Wilhelm et al., 1995) as well as by direct measurements onboard (Lemaire et al., 1997). The point spread function of the telescope is so narrow that usage of the 0.3" or 1" slits with the slit jumps in the EW direction for 0.7" – 1.5" could completely change the area observed on the solar surface. Therefore the standard rotation compensation scheme performed with such jumps is *insufficient* for the oscillations studies.

The best way how to overcome this difficulty is to prepare the SUMER observations with more sophisticated rotation compensation schemes than the standard one (Appendix B in Wilhelm et al., 1995). The first way is to exploit the possibility of a user's rotation compensation scheme, selecting the appropriate time period after which a 0.76" correction step will be performed in the EW direction. Another (and better) possibility is to manage the compensation using the half-step scanning property of the instrument. At first one should calculate for the actual slit position on the solar disk the time interval in which the solar surface will move just for 0.38" and then to command the slit motion for this single EW step after finishing of a set of measurements scheduled just for this period (e.g. Gouttebroze et al.,1999).

Concerning the data already acquired with the standard rotation compensation scheme the direct study of the oscillations is problematic. Only the general properties can be extracted from the power spectra of line intensities and wavelength shifts (e.g. Kučera, Curdt, Rybák et al., 1998). In order to be correct a special procedure should be used for such data : 1/ the coincidence of the derived spectral line characteristics with the SUMER EW coordinate Y has to be checked, 2/ the data acquired around the slit positions jumps with significant changes of the line characteristics should be omitted from further investigations, 3/ interpolation of the 'missing' data or a non-equidistant data procedure has to be used for the calculation of the power or phase spectra.

8. CONCLUSIONS

The instrumentally caused rotational compensation periodicities have been studied in a long time series of the chromospheric and transition region emission lines, measured by the SUMER spectrometer using the on-line standard rotational compensation scheme. The rotational compensation periodicities could influence the acquired data in such a way that a simple correction is not possible.

9. REMARK

The same RCPs effect was found also in the similar data set acquired on May 14, 1998. Only the slit width has been changed to 0.3" and the bottom part of the detector B has been used for this run. The basic time interval of the slit steps was slightly different (390 s). The corresponding frequency was therefore 2.56 mHz. Of course, the standard rotation compensation scheme was used onboard again. More details will be given by Curdt et al. (1999). The RCPs effect was pointed out also in case of some measurements, results of which have been published by Gouttebroze et al. (1999).

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REFERENCES

Balthasar, H., von Uexkühl, M., Innes, D., Gigas, D., and Wilhelm, K.: 1997, in : *1st Advances in Solar Physics Euroconference : 'Advances in the Physics of Sunspots'*, eds. B.Schmieder, J.C. del Toro Iniesta, M. Vázquez, ASP Conference Series **118**, 315

Betta, R., Hansteen, V., Carlsson, M., and Wilhelm, K.: 1997, in : *Fifth SOHO Workshop 'The Corona and Solar Wind Near Minimum Activity'*, ed. A.Wilson, ESA SP-404, 149

Carlsson, M., Judge, P., and Wilhelm, K.: 1997, *Astrophys.J.* **486**, L63

Curdt, W., Kučera, A., Rybák, J., Schühle, U., and Wöhl, H.: 1997a, in : *Fifth SOHO Workshop 'The Corona and the Solar Wind near Minimum Activity'*, ed. A.Wilson, ESA SP-404, 307

Curdt, W., Kučera, A., Rybák, J., Schühle, U., and Wöhl, H.: 1997b, in : *1st Advances in the Solar Physics Euroconference : 'Advances in the Physics of Sunspots'*, eds. B.Schmieder, J.C. del Toro Iniesta, M.Vázquez, ASP Conf. Ser., **118**, 322

Curdt, W., Kučera, A., Rybák, J., Schühle, U., and Wöhl, H.: 1999, in preparation for Solar Physics

Curdt, W. and Heinzel, P.: 1998, *Astrophys.J.* **503**, L95

Dammasch, I.E., Wilhelm, K., Curdt, W., and Hassler, D.M.: 1999, *Astron. Astrophys.* **346**, 285

Gouttebroze, P., Vial, J.-C., Bocchialini, K., Lemaire, P., and Leibacher, J.W.: 1999, *Solar Phys.* **184**, 253

Heinzel, P. and Curdt, W.: 1999, in : *3rd Advances in Solar Physics Euroconference : ' Solar Magnetic Fields and Oscillations'*, eds. B. Schmieder, A.Hofmann and J.Staude, ASP Conference Series, in press

Judge, P., Carlsson, M., and Wilhelm, K.: 1997, *Astrophys.J.* **490**, L195

Kučera, A., Curdt, W., Rybák, J., Schühle, U., and Wöhl, H.: 1998, in : *2nd Advances in Solar Physics Euroconference : 'Three-Dimensional Structure of Solar Active Regions'*, eds. B. Schmieder, C.E.Alissandrakis, ASP Conference Series **155**, 351

Lemaire, P., Wilhelm, K., Curdt, W., Schühle, U., Marsch, E., Poland, A. I., Jordan, S. D., Thomas, R. J., Hassler, D. M., Vial, J.-C., Kühne, M., Huber, M. C. E., Siegmund, O. H. W., Gabriel, A., Timothy, J. G., and Grewing, M.: 1997, *Solar Phys.* **170**, 105

Steffens, S., Deubner, F.-L., Fleck, B., Wilhelm, K., Schühle, U., Curdt, W., Harrison, R., Gurman, J., Thompson, B.J., Brekke, P., Delaboudinière, J.-P., Lemaire, P., Hessel, B., and Rutten, R.J.: 1997a, in : *1st Advances in Solar Physics Euroconference : 'Advances in the Physics of Sunspots'*, eds. B. Schmieder, J.C. del Toro Iniesta, M. Vázquez, ASP Conference Series **118**, 284

Steffens, S., Deubner, F.-L., Fleck, B., Wilhelm, K., Harrison, R., and Gurman, J.: 1997b, in : *Fifth SOHO Workshop 'The Corona and Solar Wind Near Minimum Activity'*, ed. A.Wilson, ESA SP-404, 679

Steffens, S., Deubner, F.-L., Fleck, B., and Wilhelm, K.: 1997c, in : *Fifth SOHO Workshop 'The Corona and Solar Wind Near Minimum Activity'*, ed. A.Wilson, ESA SP-404, 685

Wikstøl, Ø., Hansteen, V., Brynildsen, N., Maltby, P., Kjeldseth-Moe, O., Harrison, R. A., Wilhelm, K., Tarbell, T.D., and Scherrer, R. H.: 1997, in : *Fifth SOHO Workshop 'The Corona and Solar Wind Near Minimum Activity'*, ed. A.Wilson, ESA SP-404, 733

Wilhelm, K., Curdt, W., Marsch, E., Schühle, U., Lemaire, P., Gabriel, A., Vial, J.-C., Grewing, M., Huber, M. C. E., Jordan, S. D., Poland, A. I., Thomas, R. J., Kühne, M., Timothy, J. G., Hassler, D. M., and Siegmund, O. H. W.: 1995, *Solar Phys.* **162**, 189

Wilhelm, K., Lemaire, P., Curdt, W., Schühle, U., Marsch, E., Poland, A. I., Jordan, S. D., Thomas, R. J., Hassler, D. M., Huber, M. C. E., Vial, J.-C., Kühne, M., Siegmund, O. H. W., Gabriel, A., Timothy, J. G., Grewing, M., Feldman, U., Hollandt, J., and Brekke, P.: 1997, *Solar Phys.* **170**, 75

Wilhelm, K.:, 1997, in : *Fifth SOHO Workshop 'The Corona and the Solar Wind near Minimum Activity'*, ed. A.Wilson, ESA SP-404, 17