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Variation of the second solar spectrum with the solar cycle

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Abstract. The three Volumes of the Atlas of the Second Solar Spectrum that give thelinear polarization measured inside the limb near the heliographic poles with ZIMPOL (Zurich Imaging Polarimeter) are based on observationsdone around the maximum of the solar cycle. Indications about a possible solarcycle dependence of the Second Solar Spectrum already exist. Wepresent here some measurements obtained at IRSOL in 2006 duringperiods of low solar activity with the same instrumentation andtechnique used for the first two volumes of the Atlas. Our observations show that some spectral lines, in particularchromospheric lines, display remarkable changes, while the shapes of most photospheric lines remain unchanged.

Key words. Sun: linear polarization – Sun: Hanle effect– Sun: solar cycle – Sun: ZIMPOL

1. Introduction

The linear polarization due to scattering processes in the solaratmosphere shows spectral signatures that are very rich inphysical information. Its appearance differs dramatically from the usual intensity spectrum and it is therefore referred to as the Second Solar Spectrum. An Atlas of the Second Solar Spectrum observed near the solar poles(Gandorfer 2000, 2002, 2005) was recorded around the maximum of lastsolar cycle (cf. Fig. 1).The first two volumes of the Atlas were obtained at Istituto Ricerche Solari Locarno (IRSOL), whileVolume 3 is based on observations performed during two campaigns at theMcMath-Pierce telescope at Kitt Peak. All observations have been done with ZIMPOL (Povel 1995; Gandorfer et al. 2004; Stenflo 2006).Observing programs with ZIMPOL started in 1994, providing data recorded in selected wavelength windows during the minimum of the solar cycle (Stenflo 1996; Stenflo & Keller 1996, 1997).In Fig. 11 of Stenflo et. al. (2000) the Mg I triplet lines at 5167, 5173, and5184 Å recorded in 1995 at the solar poles are presented. The Q/I profiles show a peak in each core of the three lines. In contrast these peaks are absent or stronglysuppressed in Gandorfer's Atlas. The most natural explanation for this behaviour is a solar cycle variation of the Hanle effect due to the cycle variation of the magnetic properties of the polar regions on the Sun at the atmospheric level of formation of the Mg sc i lines. To investi-

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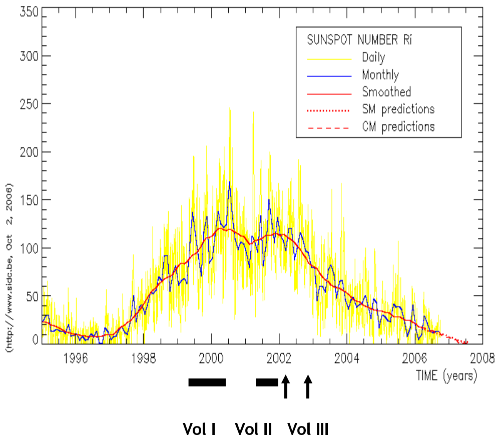

Fig. 1. Periods during which Gandorfer's Atlas of the Second Solar Spectrum were recorded, related to the phase of the solar cycle by comparing with the Sunspot Number (source SIDC, Solar Influences Data analysis Center in Brussels).

gate if other lines also show acorrelation with the solar cycle we started in 2006 an observingprogram of the Second Solar Spectrum at solar cycle minimum in severalother lines and wavelength intervals.

2. Observations

Our observations were done at IRSOL with the ZIMPOL polarimeter. The technique andinstrumentation have been described in Gandorfer (2000, 2002). The ZIMPOL camera is the UV-sensitive one used in Gandorfer (2002). The ZIMPOL analyzer is composed of a piezoelastic modulator (PEM) and a polarizing beam splitter. The automatic guiding system(Küveler et al. 1998) was used to stabilize the position on the solar disk. A limb tracking device, based on a motor controlled tilt plate, is usedto correct for the image motion induced by seeing in the directionperpendicular to the solar limb.The observations were performed in the summer of 2006 in several lines. Inthe present paper we concentrate on the results in the Mg I 5184 Å and 4383 Å lines.The data reduction technique has been described in Gandorfer et al. (2004).

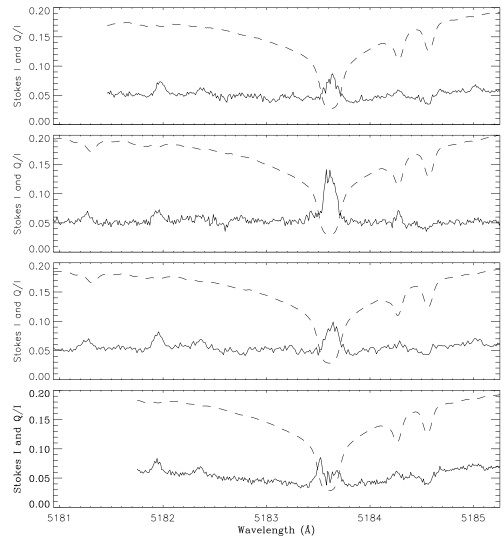

Fig. 2. Stokes Q/I profiles observed in the Mg I 5183.63 Å line (solid lines), with corresponding intensity profiles (dashedlines). The observations were done at the solar poles, about five arcsecondsinside the limb, corresponding to $\mu = \cos\theta = 0.1$. The fourplots refer to observations performed on the following days (starting fromthe top): on 22nd August 2006 at the North Pole, on 15th August 2006 atthe North Pole, on 8th August 2006 at the North Pole, and on 2nd August atthe South Pole.

3. Results

Our observations for the Mg I 5184 Å line are shown inFig. 2. We compare the Q/I profiles reported here withFig. 11 of Stenflo et. al. (2000) and with the Atlas datain Gandorfer (2000). Stenflo et al. found in 1995 a core peak in the Q/I profile with anamplitude of 0.2%, while Gandorfer in 2000 found no peak inthe same line. Our peak amplitudes vary from 0.05 % to 0.13%, and have been recordedduring a period of a few weeks. Thus, during the current solar minimum conditions, we see thereappearance of Q/I signatures at the line center of the Mg I 5184 Å line at the poles. However, short term changes of the local conditions also affect the amplitude. Interestingly the shape of the Q/I profile observedat the south pole on 2nd August (last plot in Fig. 2) indicates self-absorption.Strong Fe I lines showing core peaks in the Atlas of the Second Solar

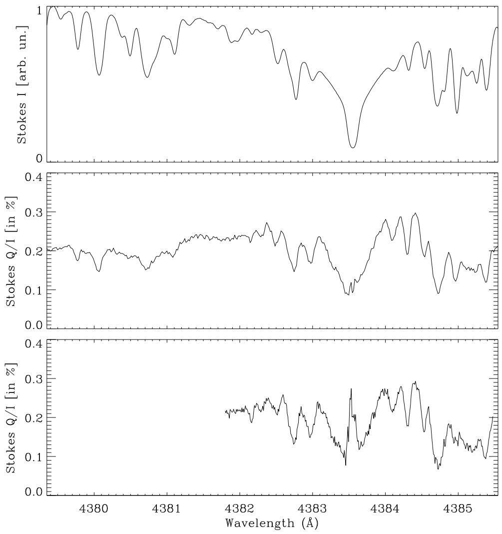

Fig. 3. Intensity and Stokes Q/I profiles for the Fe I 4383.55 Å line. The Q/I profile in the middle panel wasrecorded at the solar North Pole ($\mu = \cos\theta = 0.1$) on 10thAugust 2006. Note the absence of the central Q/I peak. The last panelshows a Q/I profile recorded at the South-East limb (thus far from the Poles) on 23rd August 2006. Here a Q/I peak can beseen, although its amplitude is lower than that of the Atlas of the Second Solar Spectrum (Gandorfer 2002)

Spectrum are now observed to have weaker or no signatures. As an example we present in Fig. 3 observations of the Fe I 4383 Å line. Gandorfer (2002) found a core peak in the Q/I profile of 0.4 %,while in our observation performed at the North Pole on 10th August2006 the peak has disappeared. An observation at the South East limb performed a couple of weeks later however showed a peak amplitude of 0.25 %.

4. Conclusions

For most of the lines the Q/I profiles that we observed in the summer of 2006, near the minimum of the solar cycle, are similar to those given inGandorfer's Atlas of the Second Solar Spectrum. Even very tiny structuresreported in the Atlas, which are just above the noise level, can bereproduced in our present observations.Several lines show variations as we have reported here.Apparently photospheric lines generally do not show any changes, whilechromospheric lines can exhibit different shapes and amplitudes.The Hanle effect is likely to be at the origin of this behavior. This wouldmean that global variations of the magnetic field related to thesolar cycle are involved, and that we now have a new tool to investigate such cycle changes.Although less likely, cycle variations of the anisotropies of the radiation field could explain some of the changes of the Q/Iprofiles. Therefore this aspect also needs to be explored. The question now arises whether one should redo Gandorfer's Atlas during the present solar minimum. Of course this would bring important new information, but such a large project would not be feasible with the current limited resources at IRSOL. Furthermore, we have noticed that some lines are changing their shapes and amplitudes on a time scale of a few days. Thus anew Atlas would not be able to account for all such changes. The best practical solution would be to do regular observations of selected lines orwavelength sections. Coordinated observations would help to optimize the use of the facilities during the periods when they are available to observe the Second Solar Spectrum with the requiredprecision.

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