

# Variation of the Second Solar Spectrum with the solar cycle

M. Bianda<sup>1,2</sup>, R. Ramelli<sup>1</sup>, and J.O. Stenflo<sup>2,3</sup>

<sup>1</sup> Istituto Ricerche Solari Locarno, CH-6605 Locarno, Switzerland

<sup>2</sup> Institute of Astronomy, ETH Zurich, CH-8092 Zurich, Switzerland

<sup>3</sup> Faculty of Mathematics & Science, University of Zurich, CH-8057 Zurich  
e-mail: mbianda@irsol.ch

**Abstract.** The three Volumes of the Atlas of the Second Solar Spectrum that give the linear polarization measured inside the limb near the heliographic poles with ZIMPOL (Zurich Imaging Polarimeter) are based on observations done around the maximum of the solar cycle. Indications about a possible solar cycle dependence of the Second Solar Spectrum already exist. We present here some measurements obtained at IRSOL in 2006 during periods of low solar activity with the same instrumentation and technique used for the first two volumes of the Atlas. Our observations show that some spectral lines, in particular chromospheric 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 solar atmosphere shows spectral signatures that are very rich in physical 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 last solar cycle (cf. Fig. 1). The first two volumes of the Atlas were obtained at Istituto Ricerche Solari Locarno (IRSOL), while Volume 3 is based on observations performed during two campaigns at the McMath-Pierce telescope at Kitt Peak. All

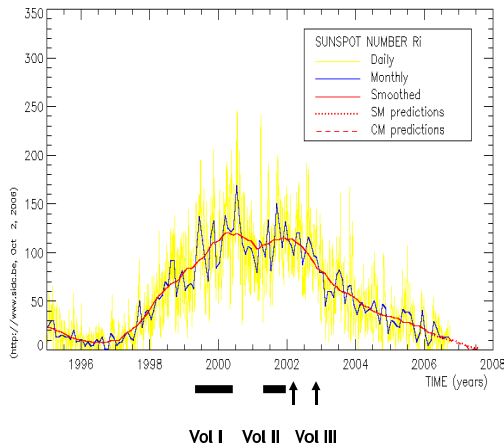
observations have been done with ZIMPOL (Povel 1995; Gandorfer et al. 2004; Stenflo 2006).

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, and 5184 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 strongly suppressed 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

---

Send offprint requests to: M. Bianda



**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).

atmospheric level of formation of the Mg sc i lines.

To investigate if other lines also show a correlation with the solar cycle we started in 2006 an observing program of the Second Solar Spectrum at solar cycle minimum in several other lines and wavelength intervals.

## 2. Observations

Our observations were done at IRSOL with the ZIMPOL polarimeter. The technique and instrumentation 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 piezoelectric 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 used to correct for the image motion induced by seeing in the direction perpendicular to the solar limb.

The observations were performed in the summer of 2006 in several lines. In the 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).

## 3. Results

Our observations for the Mg I 5184 Å line are shown in Fig. 2. We compare the  $Q/I$  profiles reported here with Fig. 11 of Stenflo et al. (2000) and with the Atlas data in Gandorfer (2000). Stenflo et al. found in 1995 a core peak in the  $Q/I$  profile with an amplitude of 0.2%, while Gandorfer in 2000 found no peak in the same line. Our peak amplitudes vary from 0.05% to 0.13%, and have been recorded during a period of a few weeks. Thus, during the current solar minimum conditions, we see the reappearance 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.

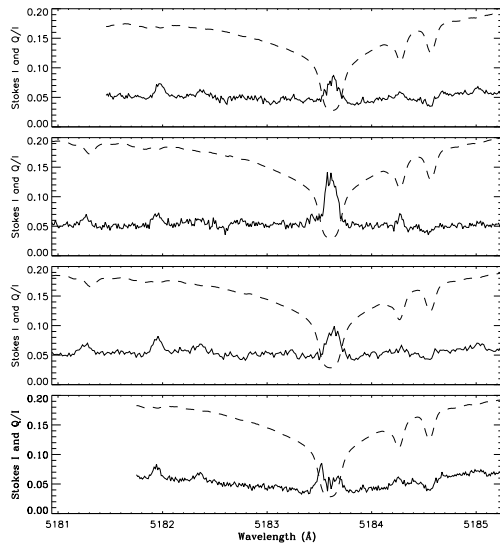
Interestingly the shape of the  $Q/I$  profile observed at the south pole on 2nd August (last plot in Fig. 2) indicates self-absorption.

Strong Fe I lines showing core peaks in the Atlas of the Second Solar 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 August 2006 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 in Gandorfer's Atlas of the Second Solar Spectrum. Even very tiny structures reported in the Atlas, which are just above the noise level, can be reproduced in our present observations.

Several lines show variations as we have reported here. Apparently photospheric lines generally do not show any changes, while chromospheric lines can exhibit different shapes and amplitudes.

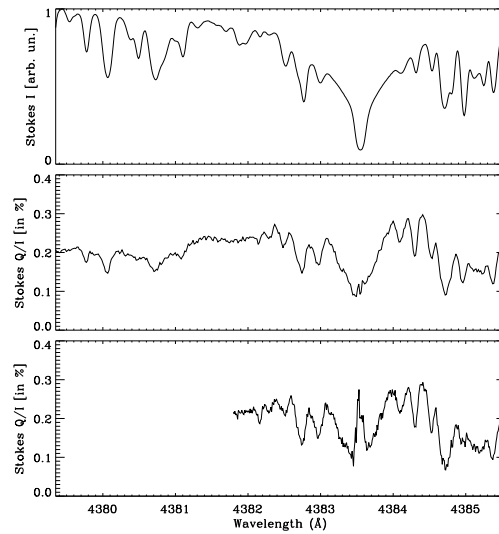


**Fig. 2.** Stokes  $Q/I$  profiles observed in the Mg I 5183.63 Å line (solid lines), with corresponding intensity profiles (dashed lines). The observations were done at the solar poles, about five arcseconds inside the limb, corresponding to  $\mu = \cos \theta = 0.1$ . The four plots refer to observations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

The Hanle effect is likely to be at the origin of this behavior. This would mean that global variations of the magnetic field related to the solar 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  $Q/I$  profiles. 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 a new Atlas would not be able to account for all such changes.



**Fig. 3.** Intensity and Stokes  $Q/I$  profiles for the Fe I 4383.55 Å line. The  $Q/I$  profile in the middle panel was recorded at the solar North Pole ( $\mu = \cos \theta = 0.1$ ) on 10th August 2006. Note the absence of the central  $Q/I$  peak. The last panel shows 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 be seen, although its amplitude is lower than that of the Atlas of the Second Solar Spectrum (Gandorfer 2002)

The best practical solution would be to do regular observations of selected lines or wavelength 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 required precision.

*Acknowledgements.* We are grateful for the financial support that has been provided by the Canton Ticino, the city of Locarno, ETH Zurich, and the foundation Aldo and Cele Daccò.

The engineering group at ETH Zurich built the ZIMPOL system and has provided technical support. The ZIMPOL program has been funded by the Swiss Nationalfonds, grant no. 200020-109159/1.

## References

Gandorfer, A. 2000, The Second Solar Spectrum, A high spectral resolution polarimetric survey of scattering polarisation at

- the solar limb in graphical representation,  
Vol. 1: 4625 Å to 6995 Å (Zurich: vdf, ISBN  
3 7281 2764 7)
- Gandorfer, A. 2002, The Second Solar  
Spectrum, A high spectral resolution polari-  
metric survey of scattering polarisation at  
the solar limb in graphical representation,  
Vol. 2: 3910 Å to 4630 Å (Zurich: vdf, ISBN  
3 7281 2844 4)
- Gandorfer, A. 2005, The Second Solar  
Spectrum, A high spectral resolution polari-  
metric survey of scattering polarisation at  
the solar limb in graphical representation,  
Vol. 3: 3160 Å to 3915 Å (Zurich: vdf, ISBN  
3 7281 3018 4)
- Gandorfer, A., et al. 2004, A&A, 422, 703
- Küveler et al. 1998, Sol. Phys., 182, 247
- Povel, H. 1995, Optical Engineering, 34 1870
- Stenflo, J. O. 1996, Sol. Phys., 164, 1
- Stenflo, J. O. 2006, these proceedings
- Stenflo, J. O., & Keller, C. U. 1996, Nature,  
382, 588
- Stenflo, J. O., & Keller, C. U. 1997, A&A, 321,  
927
- Stenflo, J. O., Keller, C. U., & Gandorfer, A.  
2000, A&A, 355, 789