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Variability of the Mn I 539.4 nm solar spectral line parameters with solar activity

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Abstract. The time analysis of Mn I 539.4 nm parameters, observed in solar flux spectrum, shows high degree of correlation with sunspot area and Mg II c/w index time spectra. The more pronounced correlation between equivalent width of this line with Mg II index implies that bright magnetic elements are important source of the line parameters variation. We synthesized line profiles, taking into account the coverage of solar surface with different features, at various solar activity levels and compared them with observations. The result shows very good correspondence between modelled and observed change.

Key words. Sun: variability – Sun: atmosphere – Sun: observation

1. Introduction

The variability of Mn I 539.4 nm line parameters, equivalent width and central depth, was recognized for the first time on the basis of full-disk observations at Kitt Peak during the period 1979-1985 (Livingston and Wallace 1987). It was concluded that its equivalent width displays an increase of more than 1% and correlates well with the Ca K line intensity. These results were confirmed in a report based on extended data (Livingston 1992). The line was also included in the "Belgrade Program for Monitoring of Activity-sensitive Spectral Lines of the Sun as a Star", which started in August 1987 (Vince et al. 1988). Analysis of the line profiles acquired during the period 1994-2002 as a part of this program, show that relative variation of the equivalent width from minimum to maximum of solar activity was 1.4%, while the variation of the central depth was 2.3% (Danilovic and Vince 2004). For the explanation of this behavior Doyle et al. (2001) proposed the sensitivity of Mn I 539.4 nm line to the optical pumping of the other manganese line which overlaps with Mg II k. On the other hand, observations of the line in spatially resolved parts of the solar disk suggest that variability could be caused by the variations of solar surface coverage with different features (Vince et al. 2005). Good correlation exists between spectroheliogram taken in the core of this line and magnetogram of the same area (Malanushenko et al. 2004).

This fact, as a previous one, inspired us to model the change of Mn I 539.47 nm line parameter with solar activity using the MDI images for features identification. The first result are given in the section 3. In the section 2 we present results of the search for periodic change at different time ranges. We are pointing to a possible connection with changes in solar activity proxies.

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2. Time Analysis

Observations of the Mn I 539.4 nm solar spectral line in the full disk irradiance spectrum were performed from 1979 to 1992 and then again have started regularly from 1998, at Kitt Peak Observatory with the the double-pass spectrometer at the MacMath Telescope (Livingston 2004). The first data sample of line parameters covers the period of 4993 days, with frequency of few days per month. Because of the irregular time sampling of the data we used CLEAN algorithm (Roberts et al. 1987; Baisch et al. 1999) for the time analysis. Results obtained after optimal number of iterations (Danilovic et al. 2005) are shown in Fig. 1(a,b). The same is performed for Greenwich total sunspot area and Mg II c/w index (version 9) and the results are shown in Fig 1 (c,d). The most pronounced peak present in all spectra is a result of 11-year change. Peaks found around 900 days (2.4 years) could be identified as a result of quasi-biannual change recognized in various solar indices and geophysical data (Djurovic and Paquet 1993; Troshichev and Gabis 1998; Polygiannakis et al. 2003). The difference between spectra is most pronounced for intermediate-term changes. This may be caused by the time sampling of Mn I 539.4 nm line observations. The same can be stated for the periods shorter than 20 days (Danilovic et al. 2005). Comparison of spectra around periods of 27 days suggest that rotational modulation of the line parameters change, especially equivalent width, is more similar to change of Mg II index. This implies that bright magnetic elements, faculae and network could be important sources of the Mn I 539.4 nm line variability. Correlation coefficients of the line parameters and Mg II index are -0.88 for equivalent width and -0.85 for central depth. Values are little lower, -0.78 and -0.83 respectively, for observations from 1998 to 2004. Apart from the fact that second data sample is considerably smaller, the difference in correlation coefficients in these two intervals could be of instrumental origin or caused by the fact that different solar activity levels are covered by observations.

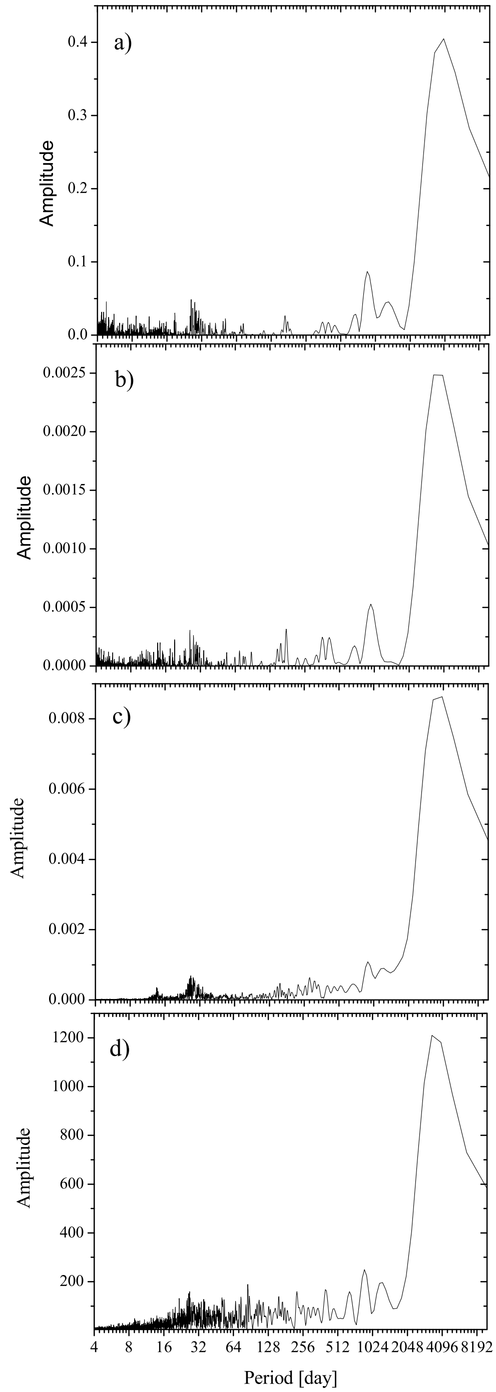

Fig. 1. The results of time analysis of Mn I 539.4 nm line parameters: equivalent width (a) and central depth (b), Mg II c/w index (c) and Greenwich total sunspot area (d).

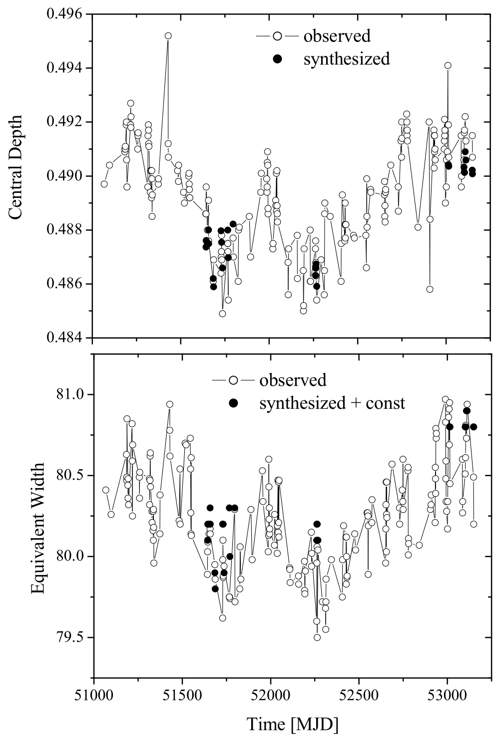

Fig. 2. Comparison of synthesized and observed central depth and equivalent width (constant of 3.7 mA is added to synthesized values).

3. Variability Modelling

To estimate how much the change of features at the solar surface affects the Mn I 539.4 nm irradiance, we combined theoretically calculated emergent spectral intensity with corresponding filling factors. Intensities at 10 heliocentric angles were calculated for the model of Mn I atom with 65 levels (Vitas 2005). Hyperfine structure was included for 37 lines. Data were taken from NIST archive. Radiative transfer calculations were performed using MULTI code (Carlson 1992) with different model atmospheres (Fontenla et al. 1999).

For identification of different features, SoHO/MDI (Scherrer et al. 1995) full disk magnetograms and continuum images were used. We followed Wenzler et al. (2004) and used the same brightness thresholds for umbrae and penumbrae identification. After employing the Gaussian filter with halfwidth of 2 pixels on a low rate full disk 1-min magnetograms we included every pixel with intensity above threshold in a network/facular distribution. Taking into account results for center to limb variations obtained by Ortiz et al. (2002), as a criteria for faculae and network separation we used $B/\mu = 80$ G as a limit, were B is a magnetogram sinal and μ cosines of the heliocentric angle. Every pixel from network/facular distribution with B/μ lower then the limit is considered to be a part of the network and every other to be a part of a faculae. The Mn I 539.4 nm irradiance was than calculated as a sum:

$$F(\lambda) = \sum_{structure}^{5} \sum_{\mu=1}^{10} I_{structure}(\lambda, \mu). \quad (1)$$

For different features: umbrae, penumbrae, quiet sun, AR faculae and network model we used S, A, C, H and F atmospheric model by Fontenla et al. (1999), respectively. In this way we obtained Mn I 539.47 nm line parameters for 26 days at different solar activity periods and compared them with observed values. Results for equivalent width and central depth are shown in Fig. 2. The relative change of line parameters from local maximum to local minimum of solar activity is well covered by the model.

4. Conclusion

Time analysis of long term Mn I 539.4 nm line observation shows that change of its parameters is very similar to chromospheric change of the Mg II c/w index. To estimate whether this high correlation of the Mn I 539.4 nm line with Mg II index is just result of optical pumping, we simulated the change using synthesized profiles of Mn I 539.4 nm line calculated without direct influence of Mg II k line and combined it with features coverage taken from full-disk images. Result show that modelled change agrees with observed one. Therefore, no additional component (like an optical pumping) is necessary to reproduce the increase in equivalent width and central depth of the Mn I 539.4 nm line from local maximum to local minimum of solar activity. Disagreement on daily basis could be caused by false matching of atmospheric models with detected features or by errors in procedure for feature identification. The very good correspondence between model and data implies that optical pumping is not the crucial mechanism of Mn I 539.4 nm line profile variation with solar activity.

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