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On the sensitivity of FeI 617.3 and 630.2 nm line shapes to unresolved magnetic fields

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Abstract. Our study was aimed at obtaining line diagnostics sensitive to effects of small scale magnetic features that are unresolved in observations. We studied the dependence on the magnetic flux of parameters describing the two Fe I lines at 630.2 and 617.3 nm. In particular, we analyzed the line core intensity (IC), full width half maximum (FWHM), and equivalent width (EQW) of Stokes I in NOAA 11172 observed with IBIS at the Dunn Solar Telescope on March 17th, 2011. Our results show that IC is sensitive to both temperature and magnetic flux variations, while FWHM is sensitive mostly to magnetic flux variations. The EQW is almost insensitive to magnetic flux and mostly sensitive to temperature. Variations of a few percents of line parameters are found in data spatially degraded to represent quiet Sun, disk-centre conditions in medium resolution observations. Such variations can be observed with instruments as SOLIS/VSM, SDO/HMI, HINODE/SOT. Shapes of investigated lines can therefore be employed to investigate physical properties of quiet Sun regions, and in particular to disentangle magnetic and thermodynamic effects an d their variations over the magnetic cycle.

Key words. Sun: photosphere – Stellar: atmospheres – Sun: magnetic cycle

1. Introduction

It is well established that solar irradiance variations are modulated by the presence of magnetic features over the solar surface. More controversial is the role played by the quiet Sun, whose contribution might change because of subtle changes of unresolved magnetic flux within these regions, or because of small changes of the stellar effective temperature. Such changes have been claimed, for instance, to account for measurements of long term variations of total solar irradiance (Fröhlich 2011) or of eleven-year variations of spectral irradiance (Fontenla et al. 2011) not reproduced by current modeling .

The origin of the quiet-Sun magnetic field is also controversial, as it is not clear yet whether it results from the decay of active regions, turbulent dynamo effects or both (e.g. Lites 2011; Lopez Ariste & Sainz Dalda 2012).

The measurement of variations of properties of the quiet Sun, as temperature and magnetic flux, is strongly hampered by observational effects. Measurements of temporal variations of temperature would require stable abso-

Send offprint requests to: S. Criscuoli lute photometric observations of the solar disk over years, while investigations of magnetic field properties are hindered by the fact that the small-size magnetic features that are known to permeate the solar surface (Bonet et al. 2012), are unresoved on full-disk images usually employed for long term studies.

Moreover, properties of magnetically sensitive lines are modified by both changes of temperature and magnetic flux. In particular, the presence of magnetic field influences the emitted radiation in magnetically sensitive lines directly, by the Zeeman effect, and indirectly, by changing the thermodynamic properties of the plasma (e.g. Fabbian et al. 2010). Analyses of line shapes have been therefore employed to investigate properties of quiet Sun (e.g. Stenflo & Lindegren 1977; Livingston et al. 2007; Penza et al. 2004).

Here we present a method, based on the analyses of FeI 617.3 and 630.2 nm line shapes, that allows to disentangle magnetic from thermodynamic variations. We show the feasibility of the method by the analysis of data acquired with the IBIS at the Dunn Solar Telescope.

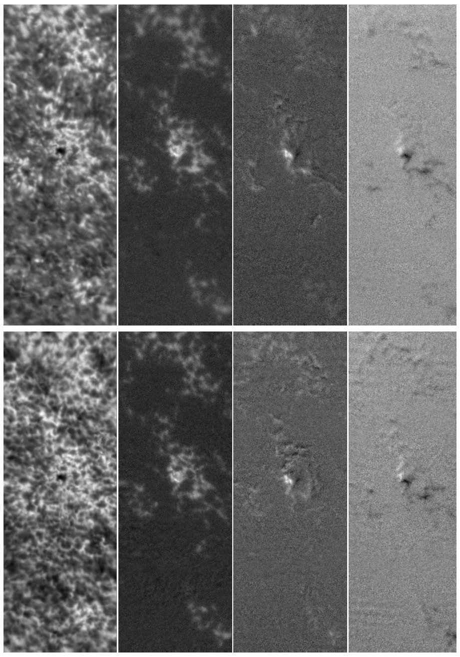

Fig. 1. Examples of the four Stokes images obtained at the 617.3 nm (top panel) and 630.2 nm (bottom panel) after data reduction. Each panel shows from left to right the I (at line core), Q, U, V (at left line wing) images, respectively.

2. Data

A facular region and a small pore located at [16.5N,10.3E] in between the leading and following parts of NOAA 11172 were observed on March 17th, 2011, with the IBIS (Cavallini 2006; Reardon & Cavallini 2008) at the NSO Dunn Solar Telescope.

The data consist of 60 spectropolarimetric scans of the FeI 617.3 and 630.2 nm lines and simultaneous White Light (WL) frames, each line was sampled at 22 spectral positions.

Images were reduced and compensated for instrumental blue-shift, for instrumental polarization, and for residual seeing-induced aberrations by standard calibration procedures (Viticchié et al. 2009; Judge et al. 2010). Reduced data, an example of which is illustrated in Fig.1, were employed to investigate the effects of magnetic flux on the shapes of the two lines.

Synthetic frames characterized by increasing average magnetic flux values were also derived from the IBIS data by replacing the line sampling measured in image pixels with the average line profile obtained in quiet sun regions. These frames were employed to investigate the effects of magnetic flux on the shapes of the two lines measured in moderate spatial resolution data.

Finally, obtained results were interpreted at the light of results from synthesis of the two FeI 617.3 and 630.2 nm lines obtained through one-dimensional atmosphere models (Fontenla et al. 1999) with the RH code (Uitenbroek 2002).

3. Results

Figure 2 shows the magnetic flux dependence of the Core Intensity (IC, hereafter), Full Width at Half Maximum (FWHM, hereafter) and Equivalent Width (EQW, hereafter) of the two FeI lines. The magnetic flux was estimated

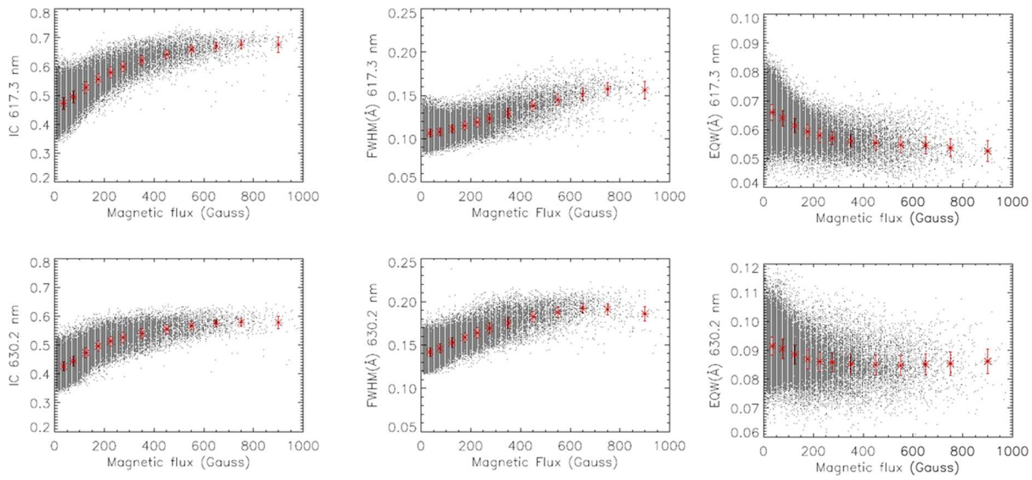

Fig. 2. Dependence of line parameters on magnetic flux. Top: 617.3 nm line. Bottom: 630.2 nm line. From Criscuoli et al. (2013).

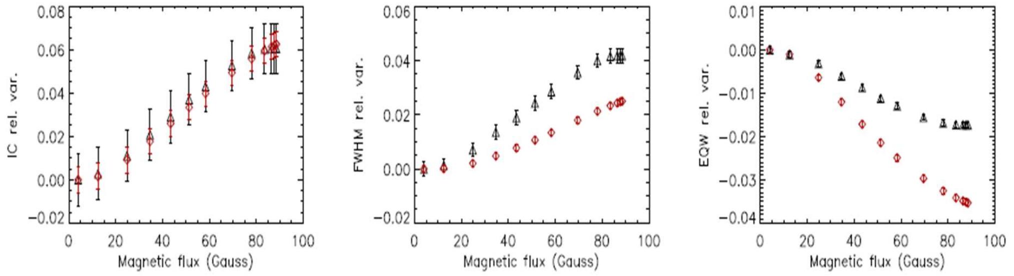

Fig. 3. Relative variation of line parameters with respect to average magnetic flux obtained from synthetic images mimicking moderate spatial resolution data. Diamonds: 617.3 nm line. Triangles: 630.2 nm line.

with the Center of Gravity method (Rees & Semel 1979). We note that IC and FWHM increase with the magnetic flux, while EQW decreases. Comparison with results from numerical synthesis (discussed in detail in Criscuoli et al. 2013) shows that for IC the trends reflect both the Zeeman splitting and the temperature effects, whereas the increase of the FWHM is mostly the result of the Zeeman broadening. Variation of the EQW is negligible at the values of magnetic flux investigated, so that the observed decrease must be ascribed to temperature variations induced by the presence of magnetic field concentrations. It is interesting to note that the three line shape parameters show saturation with the magnetic flux density. Results obtained from numerical models of aggregations of magnetic flux tubes (Criscuoli & Rast 2009), suggest this trend to be a signature of both the presence of unresolved magnetic structures (at lower magnetic flux values) and of the clusterization of elemental magnetic features (magnetic flux values after the saturation). This result confirms the recent finding by Viticchié et al. (2010).

Plots in Fig. 3 show the dependence of the relative variation of the average line properties on the average magnetic flux obtained from the synthetic frames described in Sec. 2. In particular the plots show the relative variations of line properties with respect to a frame characterized by a 5 Gauss average absolute flux. The plots show that variations of a few percent are found even for an increase of average magnetic flux of the order of tens of Gauss, which correspond to the typical values of flux thresholds employed in irradiance reconstruction to define quiet Sun regions (e.g. Fligge et al. 2000; Ball et al. 2011). For IC, variations are comparable for the two lines. In the case of FWHM, larger variations are found for the 630.2 nm, whereas in the case of EQW larger variations are found for the 617.3 nm. The 630.2 nm line is therefore more favorable for investigating magnetic field variations, while the 617.3 nm is more suitable for investigating thermodynamic variations.

4. Conclusions

The amount of variations of line shape parameters due to the presence of unresolved magnetic flux that we found should be measurable with instruments like HINODE/SOT, SOLIS/VSM and SDO/HMI. Our results indicate that, since the EQW is almost insensitive to magnetic flux variations, it would be possible to disentangle thermal and magnetic effects by comparing variations of different properties of the two Fe I photospheric lines. For instance, a decrease over the magnetic cycle of EQW together with an increase of FWHM would indicate variations of quiet Sun temperature induced by the presence of unresolved magnetic features. By contrast, a decrease of both the EQW and the FWHM would indicate an increase of the effective temperature of the plasma.

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