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How good is the Ca II K as a proxy for the magnetic flux?

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Abstract. We have coaligned near-simultanous full disk PSPT images and SOLIS longitudinal magnetograms of the solar photosphere in order to determine the relationship between the Ca II K intensity and the magnetic flux (δI_K vs $|B/\mu|$). We obtain a power-law relationship with an exponent of 0.66. This relationship allows us to use the Ca II K intensity as a proxy for the magnetic flux density for those periods when it is difficult to find both good quality magnetograms and photometric images of the Sun. Finally, we discuss the physics behind the behaviour of the contrast as a function of magnetic flux for the three PSPT wavelengths.

Key words. Sun: chromosphere – Sun: faculae, plages – Sun: magnetic fields – Sun: photosphere

1. Introduction

Comparison between Ca II K images and magnetograms shows a strong association between bright features in the Ca line and strong magnetic fields. Solar surface magnetic fields are thought to be responsible for most of the observed irradiance variability (e.g., Lean et al. 1998). However, is not always easy to find simultaneous, good quality magnetograms and intensity image pairs in order to study the radiative properties of magnetic elements. We investigate here the correlation between the Ca II K intensity and the magnetic flux density, in order to determine if the Ca II K emission can be used as a proxy when there is no easy access to magnetic flux data.

This flux-flux relationship has been previously studied by Schrijver and Harvey (1989); Schrijver et al. (1989); Schrijver (1993); Harvey and White (1999) and Rast (2003), finding the existence of a power law with a slope around 0.6 to relate the excess K-line intensity to the absolute value of the line-of-sight magnetic flux density. Skumanich et al. (1975), however, found a linear relationship.
We discuss in this work the behaviour of the contrast as a function of magnetic flux for the three PSPT wavelengths. Since different physical processes are at work at different heights, it is expected that the contrast of non-sunspot features as a function of magnetic flux presents different behaviours for the three wavelengths. The center-to-limb variation (CLV) of the red photospheric contrast of faculae and network

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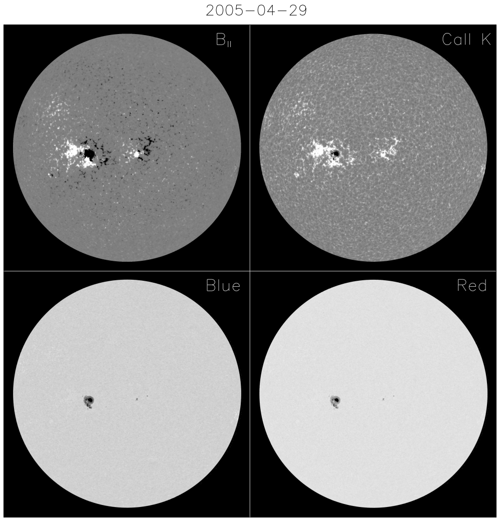

Fig. 1. Example of SOLIS longitudinal photospheric magnetogram and the coresponding PSPT images in Ca II K, blue and red. The intensity images are separated 30 min. from the magnetogram observation time.

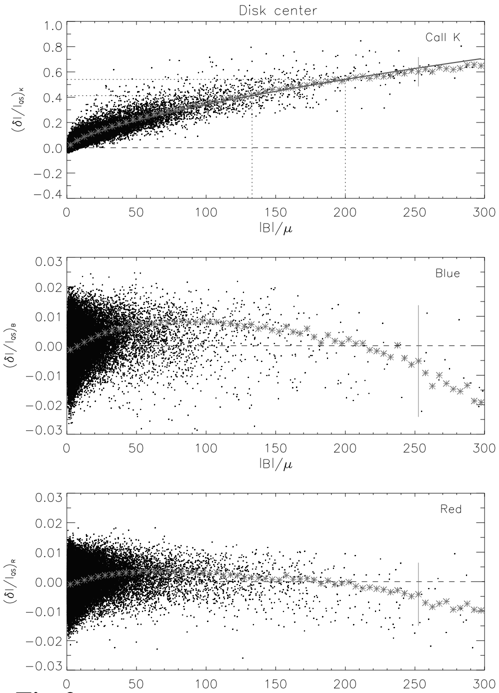

Fig. 2. Contrast of the non-sunspot pixels as a function of magnetic flux density at disk center ($0.9 < \mu < 1.0$) for Ca II K (upper panel), blue (middle panel) and red (lower panel). For all wavelengths, asteriscs represent binning and averaging of the data (dots). The bars show the $1-\sigma$ standard deviation. The curve in the upper panel shows the power-law fit for the Ca II K - $|B|$ relationship, at disk center. The dotted lines in the upper panel determine a given magnetic flux range and its corresponding Ca II K range (see Figs. 3 and 4 and text).

is discussed and compared with previous measurements.

2. Data and analysis procedure

We have coaligned nearly-simultaneous good quality PSPT photospheric continuum (409.4 and 607.1 nm) and chromospheric Ca II K (393.5 nm) images with SOLIS longitudinal magnetograms for a period of six days during 2005. The PSPT images have been carefully corrected from instrumental and limb-darkening effects, as well as rotated to align with their corresponding magnetogram. In addition, since SOLIS magnetograms have 1788×1788 pixels while PSPT images have 2048×2048, they have been scaled down to the magnetogram resolution. Figure 1 shows a sample SOLIS magnetogram and its corresponding intensity images for April 29, 2005.

3. Results

Figure 2 shows the contrast of plage, faculae and network as a function of magnetic flux density at disk center ($0.9 < \mu < 1.0$). Magnetic flux has been corrected for foreshortening by using B/μ. The following power law has been fitted to the relation between the K-line emission and the magnetic flux:

$$\left(\frac{\delta I}{I_{\mathrm{qs}}}\right)_K = 0.016|B/\mu|^{0.66} \quad (1)$$

This result is in agreement with previous results of Schrijver et al. (1989); Schrijver (1993) and Harvey and White (1999). According to Rast (2003), the Ca II K - $|B|$ correlation holds even for very low magnetic fluxes.

To see if through this relationship the Ca II K intensity can be used as a proxy for the

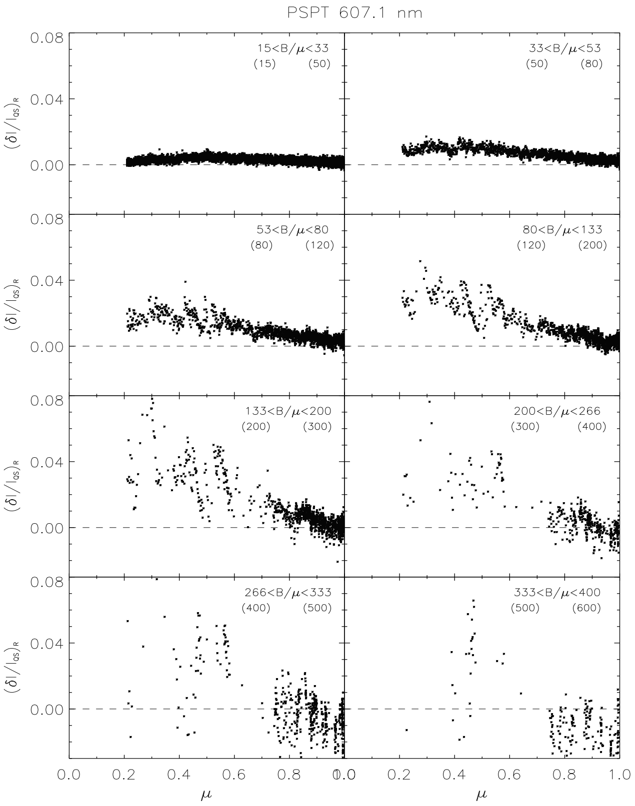

Fig. 3. Continuum contrast CLV for the non-sunspot population for eight magnetic flux ranges at 607.1 nm. Note the gradual change in the CLV of the contrast with increasing magnetic flux. The numbers in parenthesis are the corresponding MDI magnetic ranges.

magnetic flux density we have carried out the following investigation. In Fig. 3 we show the contrast CLV of the non-sunspot population for different magnetic field ranges at 607.1 nm. The CLV of the continuum contrast changes gradually with magnetic signal, such that elements with different magnetic signals exhibit a very different CLV. Fig. 4 shows again the red contrast CLV, but this time pixels have been selected and sorted according to their Ca II K emisison, not to their magnetic flux. Except in the lowest range of magnetic fluxes, the agreement between the center-to-limb variations presented in Figs. 3 and 4 shows the validity of the mapping relationship expressed in Eq. (1).

The contrast center-to-limb variations in Figs. 3 and 4 can be compared with previous contrast observations as in Ortiz et al. (2002), which used MDI/SOHO data. Taking into account the different wavelengths and spatial resolution of PSPT, SOLIS and MDI, the contrast CLVs show a notable agreement at all magnetic ranges. While MDI contrasts present a decrease close to the limb, this is harder to find in the PSPT-SOLIS contrasts. This is likely due to the effect of the lower spatial resolution of the MDI instrument, as described in Domingo et al. (2005).

4. Discussion and Conclusions

Figure 2 (top panel) shows the high correlation between magnetic fields and the K-line emission. Photospheric continuum measurements of the contrast as a function of magnetic flux (middle and bottom panels) present a very dif-

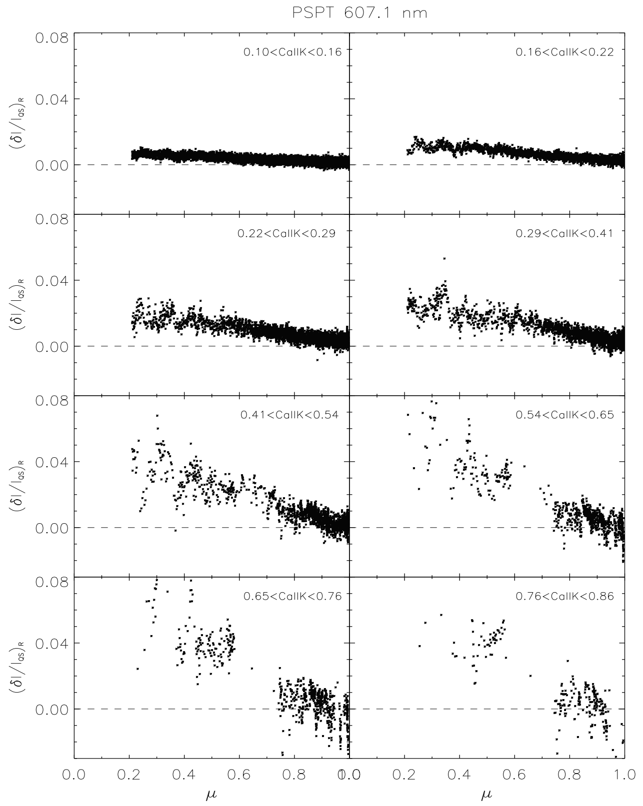

Fig. 4. Same as Fig. 3, but pixels have been selected and sorted according to their Ca II K emission in eight different ranges.

ferent behaviour. In these cases, two effects compete: the magnetic field present in evacuated flux tubes induces a decrease in the opacity, and therefore we measure radiation from deeper layers of the Sun. For sufficiently slender tubes, horizontal radiation leaking from the sides brightens the tube and the contrast increases. On the other hand, when the magnetic flux increases, i.e. the tube diameter increases, convection is supressed, the horizontal radiation does not reach the tube center, and at disk center the contrast decreases, as observed.

In view of the results presented here, we conclude that for magnetic fluxes higher that about 30 G, and perhaps much lower, the Ca II K intensity is an excellent proxy for the magnetic flux and can be mapped using the power law fit presented in Eq. (1).

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