

THE IR CONTRAST OF MAGNETIC ELEMENTS OBTAINED FROM HIGH SPATIAL RESOLUTION OBSERVATIONS AT 1.6 μm

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Abstract. We report on new improved infrared (IR) imaging observations (1.6 μm) carried out with the National Solar Observatory's Vacuum Tower Telescope at Sacramento Peak, New Mexico (NSO/SP). Examples of high spatial resolution (up to 0.4'' images are shown, and results of comparisons between infrared and continuum at 526 nm and between infrared and the locations of enhanced magnetic field ("fluxtube regions" as defined by Mg I b1 line imaging) are given and discussed. Our results indicate that, close to disk center, magnetic elements have a *positive* contrast at the opacity minimum. This is contrary to the findings of several other authors (*e.g.*, Worden 1975, Foukal *et al.* 1990). We emphasize the necessity of multi-color, high spatial and temporal resolution observations. The potential of present "almost-on-a-routine-basis" IR observations utilizing a fast video acquisition system developed at NSO/SP is pointed out.

Key words: infrared: stars – Sun: faculae, plages – Sun: magnetic fields

1. Introduction

The first attempt to measure the contrast (brightness excess or deficit) of flux tube regions at the opacity minimum was carried out by Worden (1975) using a single element detector at 1.64 μm . From his analysis of the supergranulation network a 0.7% *negative* contrast (darker than average) in magnetic regions was inferred. Koutchmy (1989) reported indications of a *positive* contrast at 1.695 μm in a facular region close to a sunspot at $\cos\theta = 0.71$. A *positive* contrast was also (statistically) found in the quiet-Sun network (1.695 μm) by Koutchmy (1978). Finally, Foukal *et al.* (1990) (using a cooled PtSi CCD) reported examples of *negative* contrast, comparing 1.6 μm images of faculae ($\geq 2.5''$ resolution) with NSO/SP Ca K spectroheliograms. Measurements in the *visible* by del Toro Iniesta *et al.* (1990) may also be interpreted to indicate negative contrast in facular regions. A tendency for a reversed (red) color index in faculae was found by Keller and Koutchmy (1990), but at the same time their analysis shows a *positive* contrast in fluxtube regions at *subarcsecond* resolution. Their analysis suggests that the "observed" negative contrast could be a result of a spatial averaging, or, conversely, of an insufficient spatial resolution. Very high resolution (0.23'') observations by Auffret and Müller (1991) show a 23% *positive* contrast of network bright points at disk center. However, Topka *et al.* (1992) report a 3% *negative* contrast up to 20° heliocentric angle

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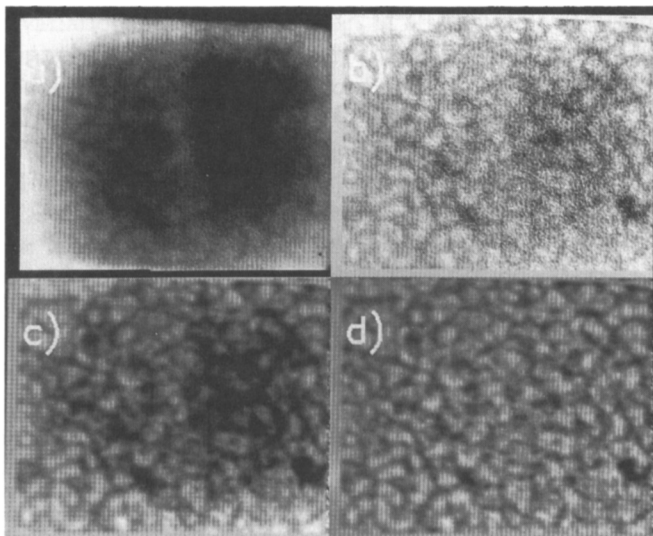


Fig. 1. *a)* Raw image after 8 bit digitization by CHIRP. *b)* Image after flat fielding by an average of 100 images taken with the telescope in motion. *c)* Image in *b* smoothed by simple 5×5 pixel bilinear interpolation (original pixel size $0.09''$). *d)* Image in *b* after unsharp masking (Wiener filter with a low frequency cutoff at $0.067 \text{ arcsec}^{-1}$). The IR images were processed in this way before the contrast analysis (Section 3) was carried out.

(and thereafter *positive*) in fluxtube regions at 500 nm, using up to $0.3''$ spatial resolution. Recently, Zirin and Wang (1992) showed that their “micropores” are dark (in visible light, disk center) relative to the intergranular lanes.

2. Observations and Preprocessing

Our observations were carried out on Sept. 11, 1990 with the Vacuum Tower Telescope (VTT) of the National Solar Observatory at Sacramento Peak. Different wavelengths were observed sequentially, see Table I. Images (256×256 pixels) were taken with an IR Vidicon N2634 and video camera at the prime focus through a $1.64 \mu\text{m}$ interference filter. Real time digitization was carried out by use of a CHIRP image processing system, allowing a variable amount of processing before storage on an optical disk. Figure 1 illustrates different steps involved in subsequent preprocessing. The wavelengths other than IR were obtained with the Universal Birefringent Filter (UBF) and Technical Pan 2415 film. Digitization of the UBF images was performed with a video CCD camera.

3. Results: Contrast of Magnetic Elements

The region under study is shown at three different wavelengths (Table 1) in Figure 2, and is located in a faint plage area close to disk center. A porule (short lifetime) is seen in the field of view. We apply the Mg I b1 (518.41 nm) filtergram (lower

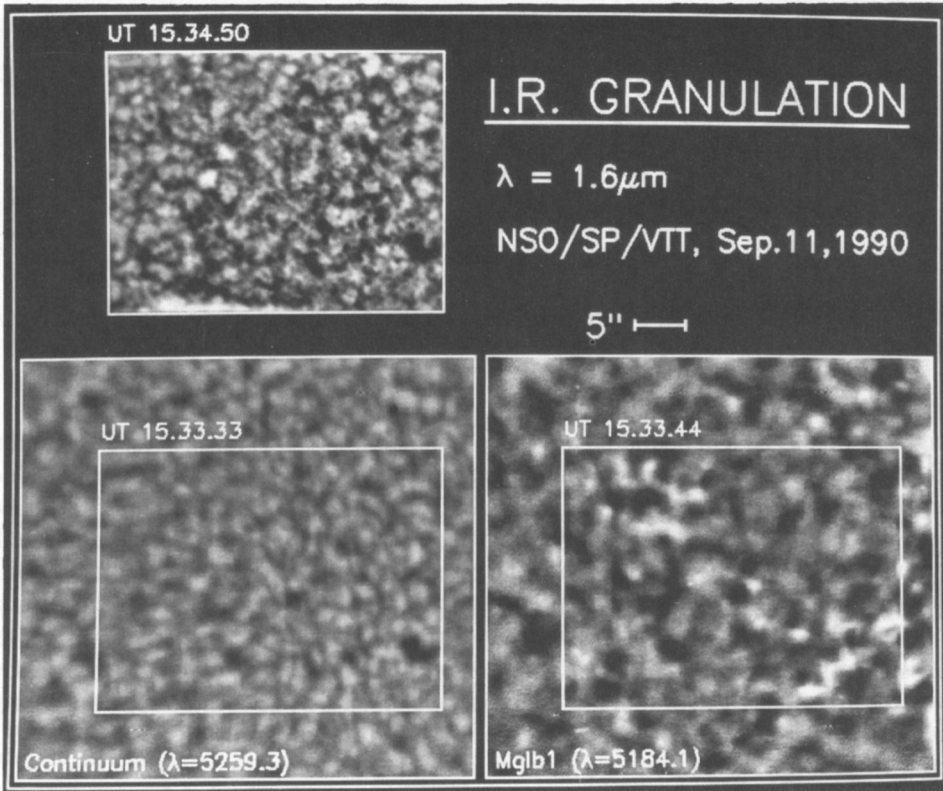


Fig. 2. Images (at 3 different wavelengths) used to study the contrast of magnetic elements. The images were obtained quasi-simultaneously (see the times given and Table I, below).

TABLE I
Sequence of Observations.

Time (UT) (h:m:s)	Spectral Region	Wavelength (nm)	FWHM (nm)	Exp. Time (s)	Line Blocking (%)
15:33:28	blue	445.124	0.0088	0.50	< 0.4
15:33:33	green	525.635	0.0131	0.10	< 0.2
15:33:38	red	606.950	0.0184	0.10	< 0.1
15:33:44	Mg I b1 + 0.4 pm	518.405	0.0127	0.30	58
15:33:51	H α	653.281	0.0220	0.02	81
15:34:50	infrared	1640	100	0.033	< 5

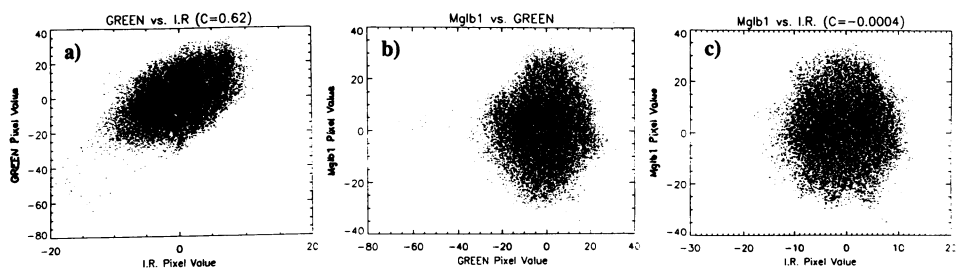


Fig. 3. Diagrams showing correlation between the 3 different wavelengths depicted in Figure 2.

right in Fig. 2) as a dependable proxy for the magnetic field strength (see Daras and Koutchmy 1983 and references therein). A correlation diagram between pixel values in the green continuum (525.63 nm) image and the IR image of Figure 2 is shown in Figure 3a, and the correlation coefficient is $c = +0.62$. Images were carefully aligned and scaled. We estimate the remaining differential image distortion due to seeing to be less than $0.5''$. Figures 3b and c show the (lack of) general correlation between Mg I b1 and green continuum ($c = +0.02$), and between Mg I b1 and the IR ($c = -0.0004$), respectively.

We investigate the properties of magnetic elements by selecting, and correlating, only those pixels in the 3 images that correspond to Mg I b1 brightness above a certain threshold. Figure 4a is a plot of the correlation computed between the visible (green continuum) image and the Mg I b1 image as the Mg I b1 brightness threshold is set successively higher. The correlation increases significantly as we leave out non-magnetic areas from the computation. This verifies the *positive* contrast (temperature excess) of magnetic elements at the photospheric level represented by the green continuum wavelength. Figure 4b shows a similar plot for $1.6 \mu\text{m}$. We find that the contrast of the magnetic elements is *positive* also at this wavelength. In the Figure are plotted the results for 4 different IR images, all showing the same general behavior.

4. Conclusion

New high resolution analysis presented here indicates that the contrast of magnetic elements is *positive* at the opacity minimum ($1.6 \mu\text{m}$). Our result is contrary to most earlier measurements (Section 1). Reasons for the discrepancies may be differences due to resolution (smearing our Fig.-2 images to $\sim 4''$ produces an apparent negative contrast, by chance, in the region of the porule), different filter properties or properties of the regions being studied, or the type of magnetic field measurement. A larger statistical sample is needed, but can now more easily be provided as the near-IR window is being opened for high resolution imaging (Koutchmy 1993, in these proceedings; see also Koutchmy 1990).

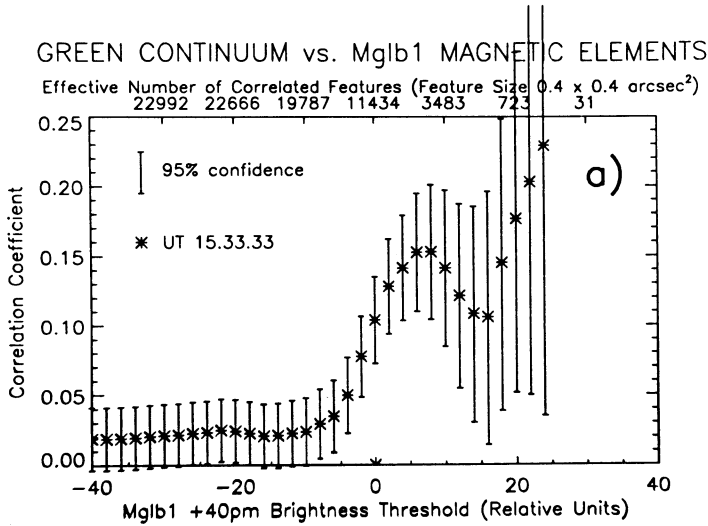


Fig. 4. a) Plots of correlation between IR and Mg I b1 as a successively higher threshold is selected for the Mg I b1 brightness. Points further to the right in the Figure are based on a subset of pixels corresponding to places where Mg I b1 brightness (and therefore magnetic field strength) is above the threshold (see Fig. 3). Error bars show a 95% confidence interval assuming the size of a resolution element to be 0.4" x 0.4". The error increases towards the right in the Figure due to a smaller number of features (see upper abscissa) being correlated.

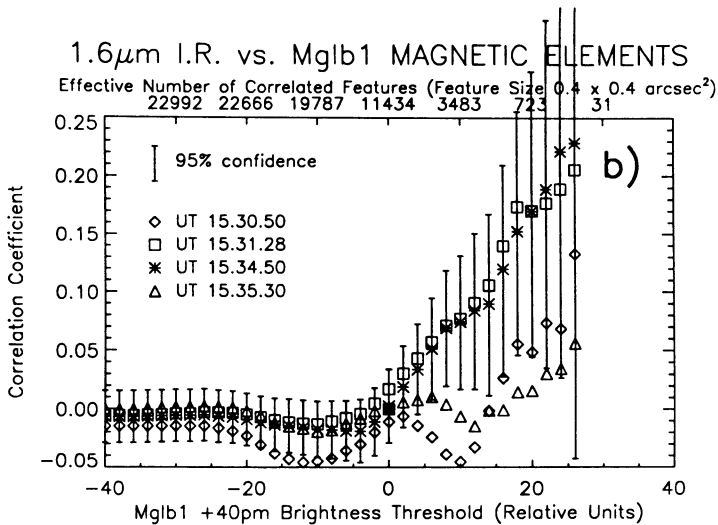


Fig. 4. b) Same as Figure 4a but now for correlation between green continuum and Mg I b1. The four different symbols in the Figure represent four different IR images.

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