CHARACTERISTISTICS OF PLAGE FRAGMENTS WITH PHOTOSPHERIC NETWORK PROPERTIES

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Abstract. Using data taken with the multi-channel magnetograph at KPNO, we demonstrate that plage regions surrounding a sunspot have thermal properties found in the photospheric network. These network-like regions existed up to the edge of the penumbra of the sunspot. Temperature gradients inferred from equivalent width fluctuations in our data do not conflict with the requirements of the theory (Parker, 1978) for flux tubes to exist at subphotospheric levels.

1. Introduction

The identity of photospheric faculae with the photospheric network and possibly with the filigree is little doubted (Mehltretter, 1974). Each is a manifestation of elementary magnetic flux tubes which extend vertically through the photosphere and upwards into the chromosphere (Chapman and Sheeley, 1968; Frazier, 1971; Skumanich *et al.*, 1975; Frazier, 1978; Elste and Teske, 1978), and the facular atmosphere has been modelled by a number of authors (see e.g. Chapman, 1977, and references cited by him).

It is usually assumed that the magnetic fields of active regions have the same properties as do the network elements. Schröter (1971) and Mehltretter (1974) implied that active regions near sunspots merely consist of densely packed network elements. It has been shown (Giovanelli and Ramsey, 1971; Frazier and Stenflo, 1978; Giovanelli and Slaughter, 1978) that downdrafts like those in the quiet network occur in association with active regions near sunspots. Frazier and Stenflo (1972) found that the magnetic properties of photospheric flux elements were the same in quiet and active regions (excluding sunspots), and independent of plage brightness. On this basis Stenflo (1975) constructed a fluxtube model applicable to both quiet and active regions, using data from the quiet network. Later, Frazier and Stenflo (1978), referring to the 'universal properties' of the magnetic elements, developed a detailed model based upon observations of active regions. The present work addresses the question as to whether plage fragments and quiet network elements have the same thermal properties.

We have used multi-channel magnetograph scans of an active region to establish that, as regards the relationship of magnetic flux with velocity, continuum brightness and equivalent widths of two Mn I lines, magnetic elements in an active region have the same structure as the quiet network at disk center.

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2. Observations and Data Reduction

2.1. Magnetograph raster scans

Data for this study are drawn from the same series of observations that were used by Elste and Teske (1978) to analyze the quiet manganese network at disk center. They have described in detail the observations, their calibration and their noise. Raster scans were made with the multichannel magnetograph (Livingston and Harvey, 1971) at the main image of the McMath telescope on Kitt Peak. Each raster covered an area of $175'' \times 78''$ arc; a $1'' \times 1''$ arc entrance aperture was used. Simultaneous measures of magnetic flux, velocity, continuum intensity and intensity in two Mn lines were made at each raster point. The latter data were converted to equivalent widths of the Mn I λ5420 and Mn I λ5395 lines.

Here we are concerned with analysis of three raster frames that were observed on May 13, 1976, in McMath plage 14203, then located at N04W22. Included in the raster frames was a large αp spot, Mt. Wilson 19582, at N00W26. Both sunspots and plage were in their third rotation. Figure 1 shows the location of one raster superposed on a Ca II K spectroheliogram.

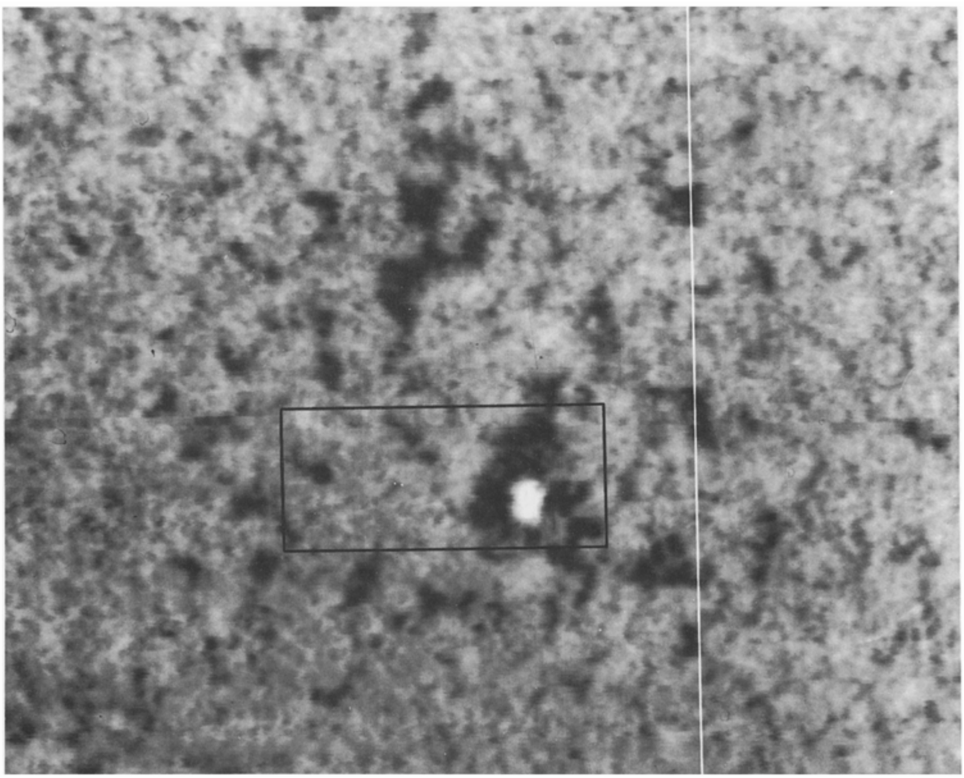

Fig. 1. Ca II K spectroheliogram taken at $12^h 52^m$ UT on 13 May, 1976. North is up, east to the left. The box outlines the raster area of Figure 3.

2.2. Average photospheric background

Velocities, continuum intensity fluctuation $\delta I_c = (I_c - \langle I_c \rangle)/\langle I_c \rangle$ and equivalent width fluctutions $\delta W_\lambda = (W_\lambda - \langle W_\lambda \rangle)/\langle W_\lambda \rangle$ are referred to the undisturbed average local photospheric background, $\langle I_c \rangle, \langle W_\lambda \rangle$. These averages were determined by the method described by Elste and Teske (1978), except that no data from the sunspot and its near vicinity was used in either of the two steps for fitting the average background.

3. Results

3.1. The network identity of plage fragments at the photospheric level

Elste and Teske (1978) established for the quiet Mn network a relation between measured longitudinal magnetic field H_0 and measured δW_λ for the Mn I λ 5395 line, deriving

$$\delta W_\lambda = (-0.626 \pm 0.057)\,|H_0|\,, \tag{1}$$

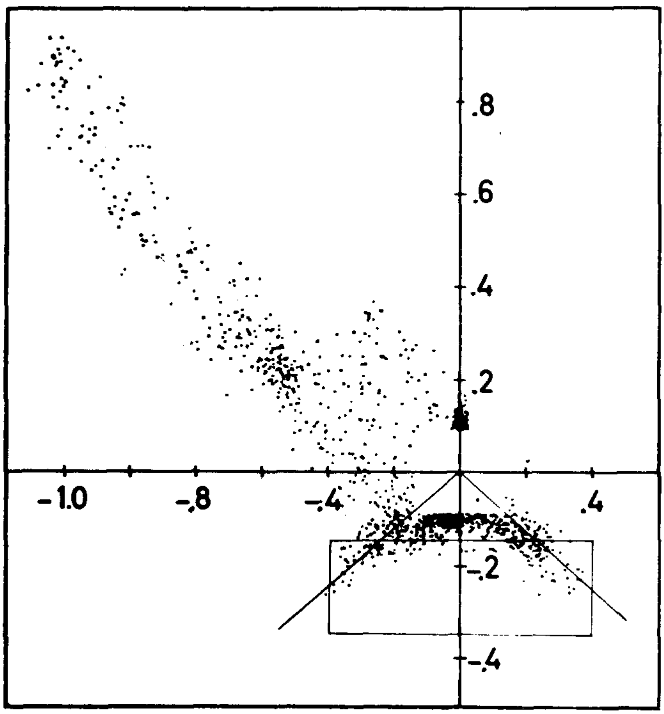

Fig. 2a. Scatter diagram for H_{obs} (abscissa, in kilogauss) and equivalent width of Mn I λ5395, δW_λ (ordinate). The linear regression relation for the quiet network, Equation (1), is plotted. Locations of the points within the box are shown in (b).

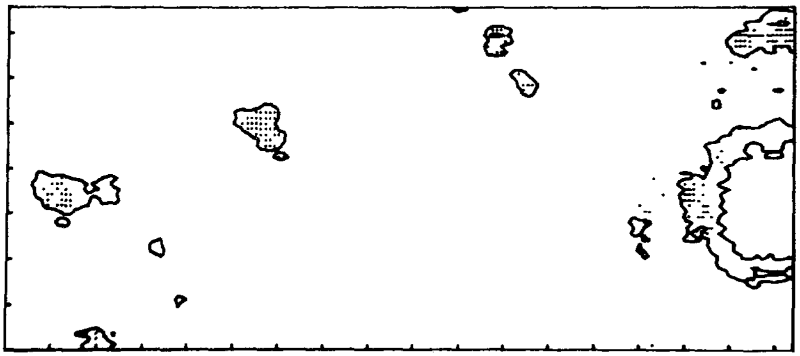

Fig. 2b. Magnetic contours are for −400, −100, and +100 G. The dots are those within the box in (a). Tick marks on the raster area's border are 10″ arc apart.

where H_0 is in units of 1000 G. Negative values of δW_λ indicate increased temperatures in the line forming layers of the photosphere. We have drawn this linear function as solid lines on the corresponding scatter diagram for one of the rasters studied here (Figure 2a) and find it is an excellent fit to these data. Data points in the upper left of Figure 2a which show the opposite correlation – an increased equivalent width associated with strong negative magnetic field – refer to the penumbra and umbra of the sunspot.

The box in the scatter diagram of Figure 2a may then be presumed to contain only those points which resemble the quiet network. The location of these points is indicated on the magnetic contour diagram of Figure 2b. The 100 G contours have been arbitrarily selected as showing the outlines of plage fragments. Upon referring to the Ca II K spectroheliogram we see that the areas containing dots are uniquely and unambiguously the plage fragments. These same results are obtained with equivalent widths of the Mn I λ 5420 line.

The clear distinction of temperature structure for sunspot and plage can be derived from the continuum and equivalent width information shown as Figure 3. The sunspot is cooler than the average photosphere in both the continuum forming and line forming layers, while the plage areas are hotter in the line forming strata with little or no distinction in the continuum forming levels.

The data indicate that there may be a correlation between continuum intensity fluctuations and magnetic field strength with the continuum being a few tenths of a percent brighter in the magnetic elements than in the average photosphere. The error bars associated with these measures are several times the mean values and contain noise not only from seeing but from the photospheric granulation as well. Our result refers to a magnetic flux range $5.3 \times 10^{17} < \phi < 21 \times 10^{17}$ maxwells (for our $1'' \times 1''$ arc aperture) and does not deviate from Frazier's (1978) measures of very weak continuum brightening made with a $2.4'' \times 2.4''$ arc aperture. It also agrees with results obtained by Elste and Teske (1978) for the quiet network.

We conclude that the thermal photospheric properties of network and plage are essentially the same.

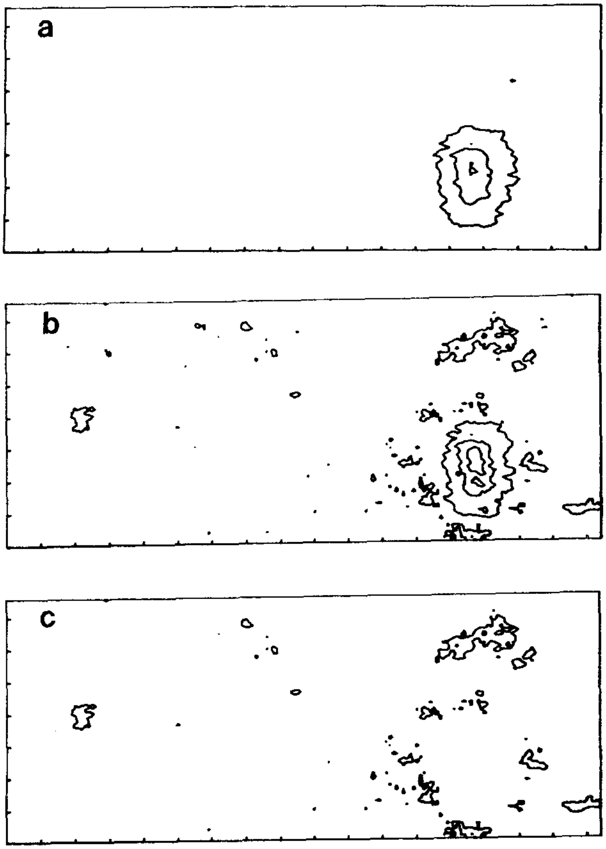

Fig. 3. (a) Contours of continuum intensity $\delta I_c = -0.1$, -0.3, and -0.6, for the raster area outlined in Figure 1. There are no contours levels in the data for $\delta I_c > +0.1$. (b) Contours of equivalent width in the Mn I λ5395 line, $\delta W_\lambda = -0.2$, -0.1, $+0.1$, $+0.3$, and $+0.6$. (c) Same as in (b), except that contours for $\delta W_\lambda = +0.1$, $+0.3$, and $+0.6$ have been omitted.

Figures 2 and 3 also show that the plage areas with network properties are found right up to the edge of the sunspot penumbra.

Parker (1978) described a process by which magnetic fields on the sun may be concentrated into thin flux tubes, which he called the superadiabatic effect. The tubes are envisioned as forming when gas which is thermally isolated from its surroundings by the field flows downward adiabatically through subphotospheric layers having a superadiabatic temperature gradient. Our data imply that the flux tubes have a higher temperature than ambient in the line forming layers and a small or zero temperature difference at continuum forming levels. Extrapolation suggests that the elements' subphotospheric temperature gradient may be less steep than outside them, consistent with the operation of the superadiabatic effect.

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