MAGNETIC FIELDS MEASURED WITH THE 10830 Å He I LINE

J. HARVEY and D. HALL
Kitt Peak National Observatory, Tucson, Arizona, U.S.A.*

Abstract. Several advantages of near infrared spectral lines for magnetic field measurements are listed. In particular, the 10830 Å multiplet of He I is well suited for observations of chromospheric magnetic fields.

New photoelectric spectroheliograms made with the 10830 Å line reveal a large amount of filamentary fine structure in active regions. This fine structure has important consequences on the interpretation of 10830 Å magnetograms. Except for an association of 10830 Å disk filaments with polarity reversals there is little correlation between absorption features and the 10830 Å longitudinal field. Comparisons of chromospheric and photospheric observations show that the chromospheric field is spatially more diffuse and weaker than the photospheric field.

1. Introduction

Many attempts have been made to observe magnetic fields in the chromosphere. These observations are difficult to interpret for various reasons:

(1) The inhomogeneous structure of the chromosphere manifest in chromospheric spectral lines has a profound effect on magnetic measurements made with such lines. This structure cannot be ignored in interpreting chromospheric magnetograms.

(2) The wings of some 'chromospheric' lines have large contributions from photospheric heights.

(3) Blending of chromospheric lines with photospheric lines reduces the relative contribution of the chromosphere to the final magnetic measurement (Zhulin *et al.*, 1968).

(4) Atomic level interference can produce polarization in chromospheric lines which affects some magnetic measurements (Lamb, 1970).

At Kitt Peak, magnetograms have been made with K_3, Hβ and Hα for several years but, as representative measurements of the magnetic field in the chromosphere, our observations are unsatisfactory because of the problems listed above. In an effort to minimize some of these problems, we examined the chromospheric lines in the near infrared spectrum. We have selected the lines of the He I multiplet (λ 10829.08, λ 10830.25 and λ 10830.34 Å) as the most suitable for chromospheric magnetic field measurements in the accessible spectrum. Since these lines are formed only in the chromosphere problem 2 is avoided and, by chance, problem 3 is also not important. Problems 1 and 4 are still important. Several Si I lines close to 10830 Å are suitable for photospheric field measurements.

The location of the lines in the infrared might seem to be a disadvantage but there are several advantages to using infrared lines compared with visible lines for magnetic measurements. Among these are:

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(1) Better seeing (Turon and Lena, 1970).

(2) Less scattered light (Staveland, 1970).

(3) Less atmospheric extinction.

(4) Better reflectivity by aluminized mirrors and, as a result, less instrumental polarization.

(5) Better magnetic sensitivity since the ratio of Zeeman splitting to line width varies roughly linearly with wavelength.

(6) Less noise produced by image motion while measuring sunspots because of the smaller contrast between umbral and photospheric intensities.

(7) Less precise optical surfaces are required.

(8) Fewer blending problems because there are fewer lines.

Some of the disadvantages of infrared lines for magnetic measurements are:

(1) Solar energy flux is smaller (by a factor of about 3 between 5000 and 10000 Å).

(2) Unless special precautions are taken, noise during a magnetic measurement with existing photodetectors is due to dark current rather than shot noise.

(3) Spectral lines tend to be weak.

Considering the good and bad features, we believe that the near infrared is a very promising spectral region for magnetic field measurements.

2. Observations

To observe at wavelengths around one micron we replaced the photomultipliers in the Babcock-type magnetograph of the McMath Solar Telescope (Livingston, 1968; Livingston and Harvey, 1970) with silicon photodiodes (Electro-Nuclear Laboratories, Type PDS-050L). Low noise preamplifiers were constructed so that the photodiodes looked electrically like photomultipliers to the rest of the magnetograph electronics.

We made spectroheliograms in addition to magnetograms by placing one exit slit of the magnetograph in the core of the line and the other exit slit in the continuum and recording the signals separately while making a raster scan.

The 10830 Å multiplet consists of three lines, two of which overlap to produce a line as much as eight times stronger than the remaining line. We used the strong line for our observations and adopted an effective Landé g-value of 1.47 which should not be in error by more than ± 0.03 due to optical depth variations. For photospheric measurements we used the 10827 Å line of Si I which has a simple triplet Zeeman pattern with a Landé g-value of 1.50.

During magnetic measurements, an effort to compensate for large scale variations of the strength of the 10830 Å line was made. We used the Doppler servo to produce a small sinusoidal wavelength oscillation of the line with respect to the exit slits at a frequency different from that used to analyze the magnetic field. By doing this we produced an artificial longitudinal Zeeman effect of known, constant strength. Any variation in the strength of the signal derived from the artificial Zeeman effect is due to a change in the observed line profile which affects the actual longitudinal field observation in essentially the same way. By dividing the actual signal by the artificial signal at each observed point, we obtain measurements of the average longitudinal Zeeman effect produced in the 10830 Å absorption features. Essentially the same technique was used on the original Climax magnetograph (Lee *et al.*, 1965).

We calibrated our observations in the usual manner by placing a circular polarizer in front of the analyzer and displacing the spectrum line on the exit slits a distance corresponding to a known magnetic field strength. Some of the observational parameters are listed in Table I.

TABLE I

Observational parameters

Parameter	Magnetograms	Spectroheliograms
Entrance aperture (arc s)	4.8×4.8	1.4×1.4
Exit slit (Å)	0.46	0.46
Integration time (s)	0.3	0.03
Modulation frequency (Hz)	10^3 (Zeeman) 45 (reference)	800
Area scanned (arc s)	163×288	160×186

3. Results

Previous spectroheliograms made with the 10830 Å line (D'Azambuja and D'Azambuja, 1938; Zirin and Howard, 1966) as well as spectra (Mohler and Goldberg, 1956) have shown the distribution of 10830 Å absorption on the disk to be very irregular. (The line strength fluctuates in a pattern similar to other chromospheric lines, i.e. strong in plages and filaments). However, the spatial resolution of previous observations of 10830 Å has not been adequate to reveal the fine structure (Giovanelli, 1967).

Figure 1 is one of our spectroheliograms taken in good seeing in which we begin to resolve fine structure. Filamentary details dominate this picture. In the lower portion of the illustration which shows the ratio of 10830 Å to continuum brightness we see that the sunspots nearly vanish. The 10830 Å absorption is still present in the locations of the spots although it is very weak in the darkest parts of the umbrae.

Figure 2 shows an older active region in which the 10830 Å absorption is weaker than in the region shown in the first figure. Except for one dark disk filament, filamentary structure is not prominent. Instead, there are extended, dark, mottled areas.

Figure 3 shows a region near the limb. The continuum picture shows photospheric faculae faintly and very little limb darkening, especially compared with the limb darkening in the 10830 Å line. Both pictures are reproduced with equal contrast. There is good, but not perfect, correspondence between the positions of 10830 Å absorption and continuum faculae. The ratio picture reveals the chromosphere as a bright band roughly 9000 km high. The sunspot does not vanish in the ratio picture, unlike the spots closer to the disk center shown in Figures 1 and 2. This behavior can be explained as a difference in the height of the spot seen in the continuum and in the

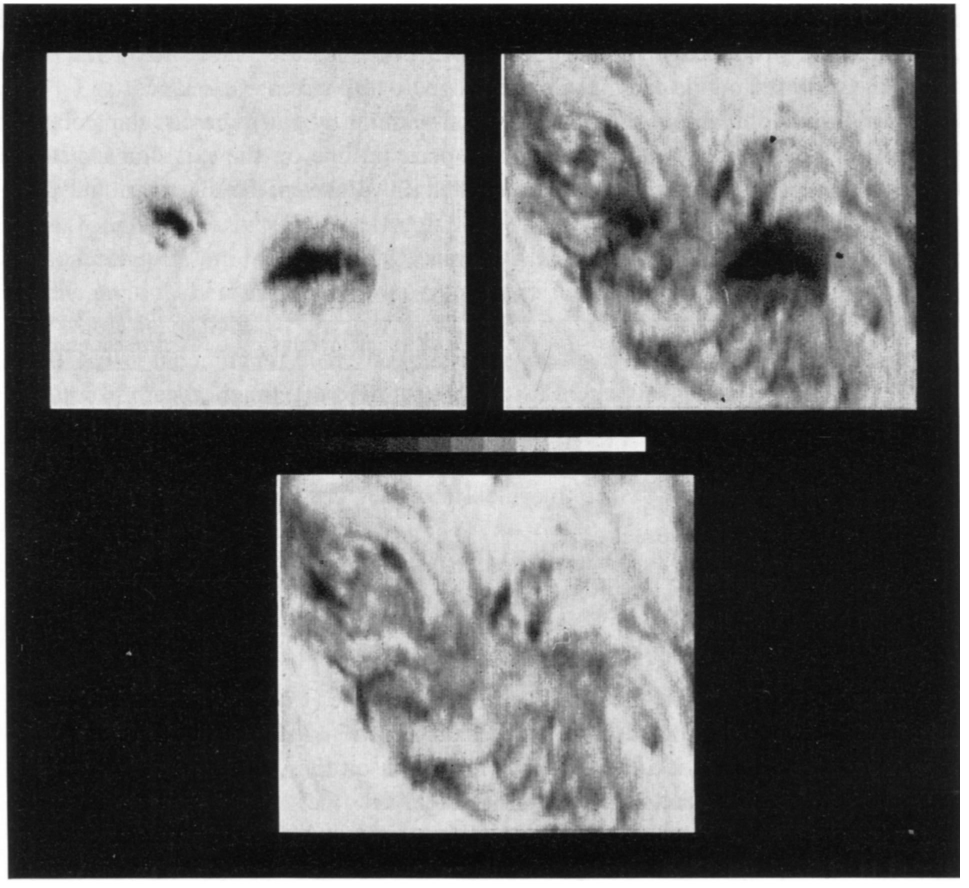

Fig. 1. Simultaneous photoelectric spectroheliograms taken on June 19, 1970 with the core of the 10830 Å line (right) and the nearby continuum (left). The lower picture shows the ratio of the core to the continuum measurements. The pictures have been generated with a computer simulating an effective photographic gamma of 4.

10830 Å line. Adopting this explanation, we find an apparent height difference of roughly 1000 km. Thus our 10830 Å observations refer to features which probably lie roughly between 1000 and 9000 km in height on the average.

Our spectroheliograms show filamentary structures (disk filaments and fibrils) as the most prominent features of active regions. While our spatial resolution is not yet adequate to clearly resolve the other mottled areas, it is probably safe to assume that better spatial resolution will resolve these areas into tiny fibrils and fine mottles similar to those visible on high-quality Hα filtergrams.

A somewhat confusing situation results from comparisons of 10830 Å magnetograms and spectroheliograms such as shown in Figures 4 and 5. We see that the strongest longitudinal fields are associated with sunspots. The darkest, filamentary features in 10830 Å, which we presume to be disk filaments, are generally well

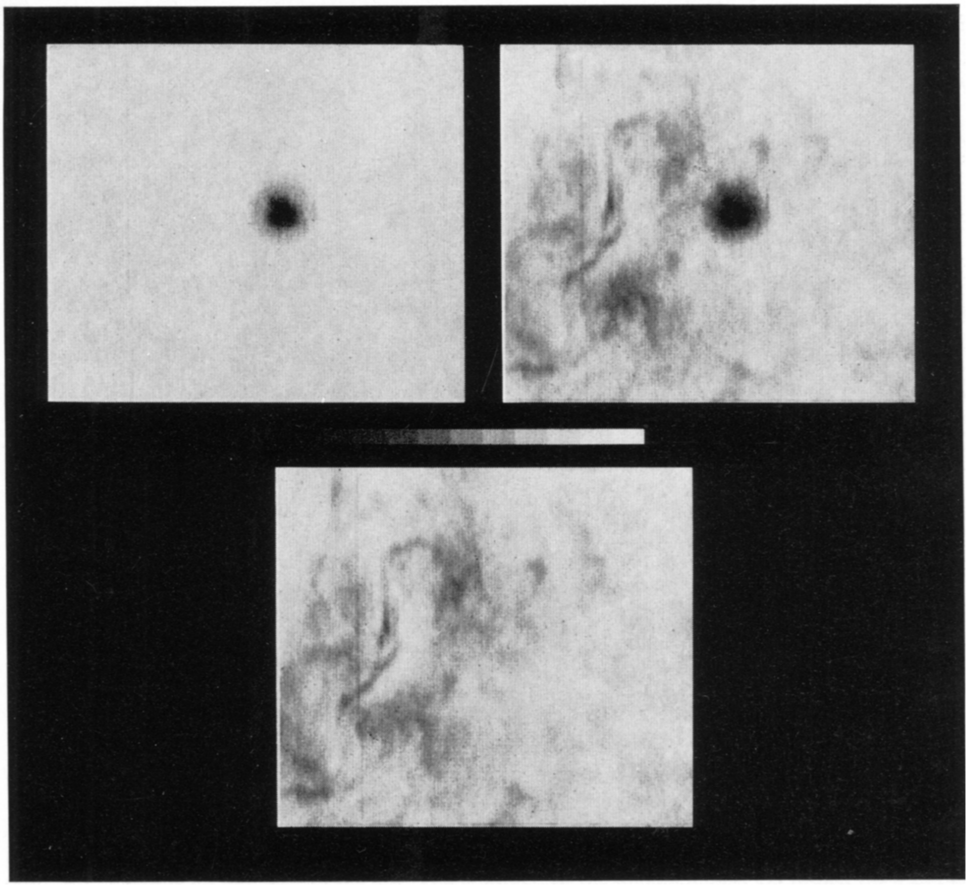

Fig. 2. Same as Figure 1 except an older active region near the disk center.

associated with reversals of the polarity of the 10830 Å longitudinal field. Beyond these two expected associations, there is very little distinct relationship between 10830 Å features and the 10830 Å magnetic field. We can see that wherever there is a significant field in 10830 Å there is also some 10830 Å absorption. But in many cases, such as the lower left center of Figure 4, the absorption is very weak even though the field is strong. In other cases, away from polarity reversals, the field is fairly weak but the absorption is relatively strong. The older active region shown in Figure 5 exhibits the same poor correlation between field strength and absorption so that the state of development of the active region does not seem to be a significant factor. Other regions we have studied show the same behavior.

Comparisons of 10830 Å and photospheric (10827 Å) magnetograms such as shown in Figures 6 and 7 give consistent results. The most obvious result is that the general pattern of fields is nearly identical. The next result, which is well shown in Figure 6, is that the average longitudinal field in the chromosphere is spatially more

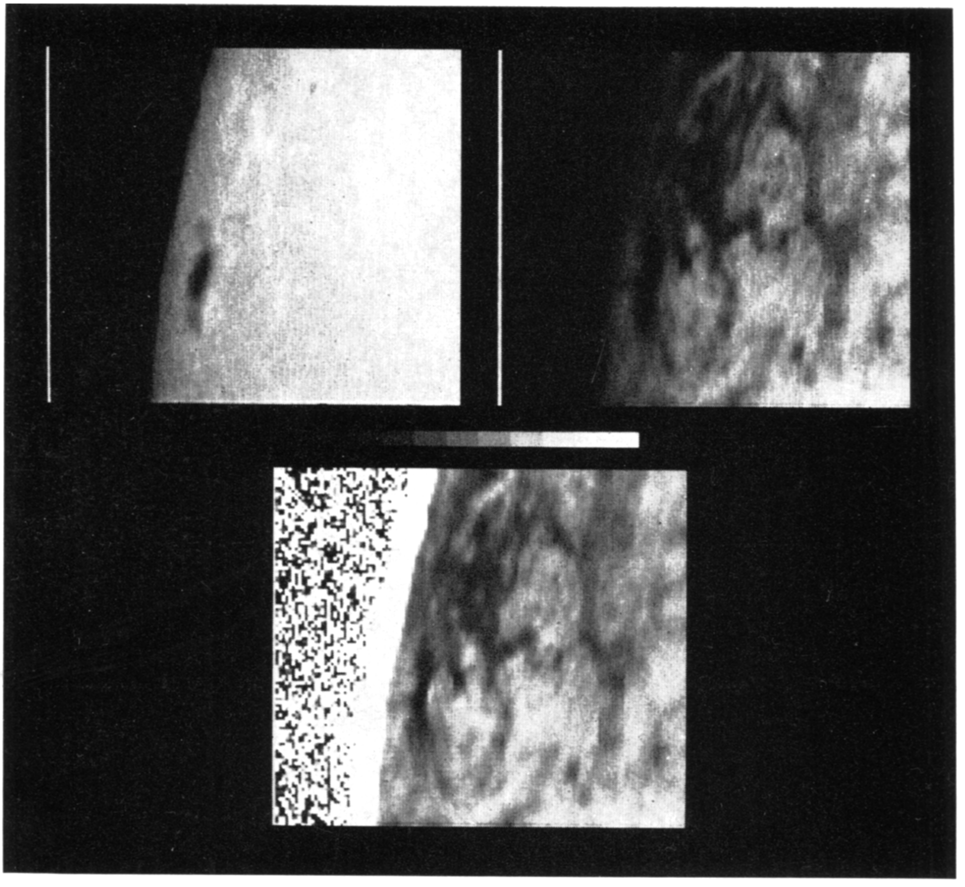

Fig. 3. Same as Figure 1 except a region near the west limb. In the ratio picture, measurements in the chromosphere above the limb show as a bright band with a height of about 9000 km. Above that height only noise is visible as checkered pattern of light and dark elements.

diffuse than the photospheric field. This is particularly clear in the contour maps. The final obvious result, which is well shown in Figure 7, is that the average longitudinal field strength we measure with 10830 Å is roughly $\frac{1}{2}$ to $\frac{3}{4}$ of the value we measure at the same point with the 10827 Å line.

4. Discussion

It is premature to attempt to construct a model of the chromospheric magnetic field from these preliminary observations. Our most serious problem is the effect of unresolved fine structures on our magnetic observations. The compensation technique we use to correct for line profile variations cannot remove the effects of unresolved

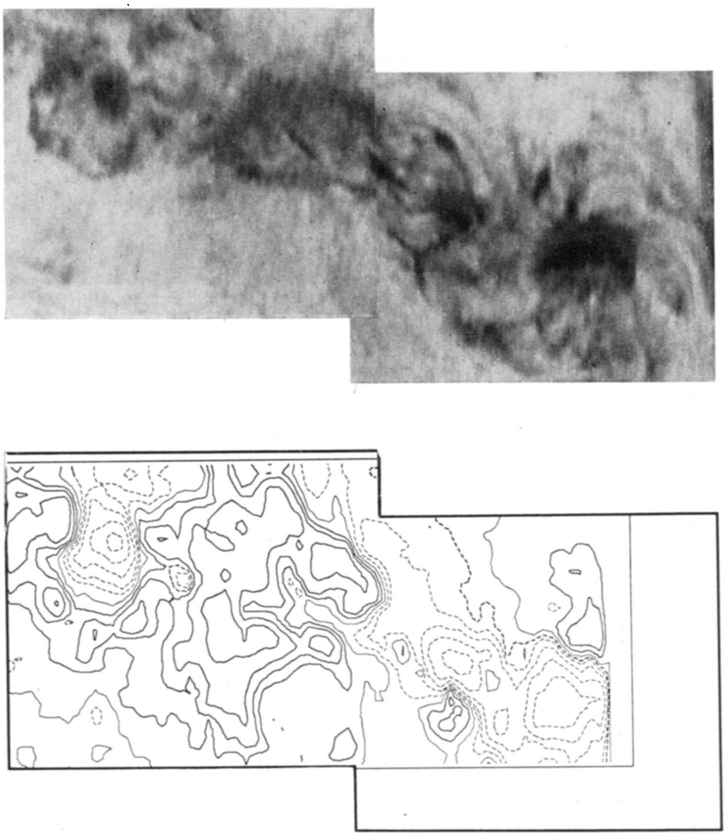

Fig. 4. Comparison of a nonsimultaneous 10830 Å spectroheliogram (top) and magnetogram (bottom). North is up and east to the left. The contours of the magnetogram are drawn for average longitudinal field strengths of 25, 50, 100, 200 and 400 G.

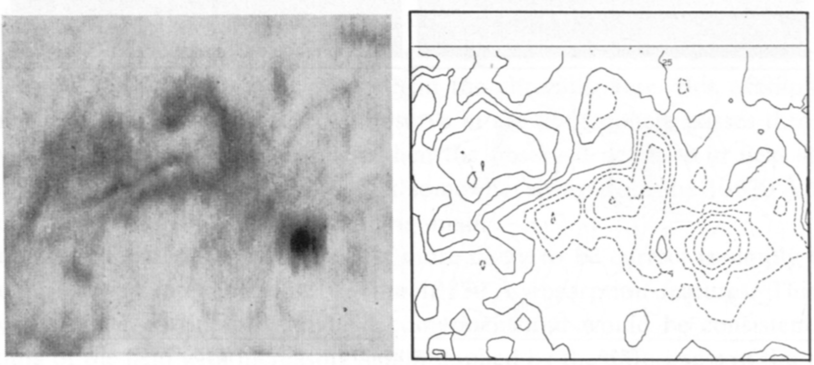

Fig. 5. Same as Figure 4 except an older active region.

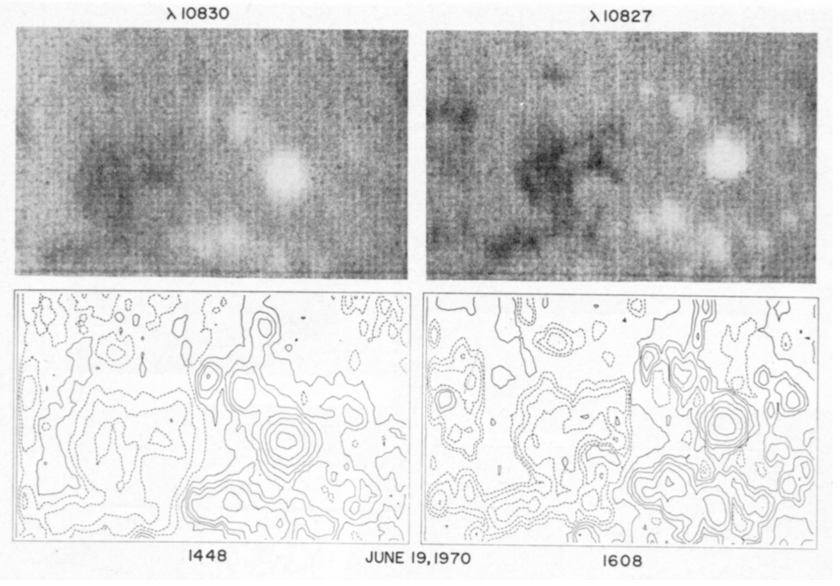

Fig. 6. Magnetograms taken with the 10830 Å line (left) and the 10827 Å line (right). In the top photographs the departure from gray is proportional to the average longitudinal field strength and polarity. The contours are drawn at values of 25, 50, 100, 200, 400, 800 and 1600 G. The field strength is underestimated in the sunspot at the right because of excessive Zeeman splitting. Note the diffuseness of the field in 10830 Å compared with 10827 Å.

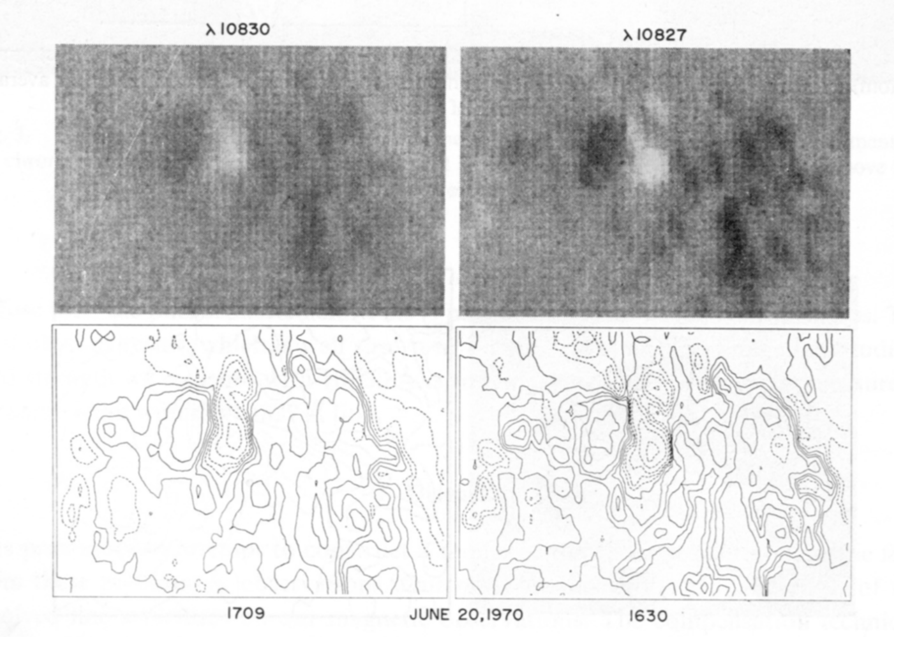

Fig. 7. Same as Figure 6. Note the weakness of the field in 10830 Å compared with 10827 Å.

fine structures and the effect on our magnetic measurements is different for the two lines we used. To illustrate, suppose we have a simple two component model of the solar atmosphere of the sort proposed by Namba (1963) and de Jager *et al.* (1966). Imagine that the magnetograph aperture is partially filled by each type of component and that one component has a longitudinal magnetic field and that the other does not. In the case of the photospheric line, suppose that the line profile does not differ significantly in the two components. Therefore in our magnetic measurement we get an equal contribution from the magnetic and nonmagnetic components and we measure a magnetic field strength which is the average of the field including both magnetic and nonmagnetic components. That is, we measure the average longitudinal magnetic field integrated over the aperture of the magnetograph. If the region is at the center of the disk this quantity would simply be the magnetic flux passing through the photosphere.

In the case of the chromospheric line let us suppose that the line is formed only in the component with a magnetic field. Then our magnetic measurement includes no contribution from the nonmagnetic components and we measure the average magnetic field *excluding* the nonmagnetic elements. Similarly if the line is formed only in the nonmagnetic elements, only they would contribute to our measurement (which would be zero in this case).

Of course, the actual situation in the solar atmosphere is not so simple as this and extreme care is necessary in interpreting our observations. We have no evidence of significant variations of the 10827 Å line profile outside sunspots so we believe that our measurements with this line actually give the longitudinal magnetic field strength averaged over our 5 arc s aperture. Since we know that the photospheric field tends to be clumped into small elements which do not completely fill our large aperture, the field strengths in these elements are always greater than the average field strengths we measure.

Our spectroheliograms in 10830 Å give abundant evidence of line profile variations so with our observing technique the 10830 Å magnetic measurements are weighted averages of the longitudinal magnetic field in those 10830 Å absorption features falling within the aperture. The weighting function is simply the relative contribution of each feature to the total observed line profile. One can now imagine many models of the 10830 Å absorption features and their magnetic fields which can explain the observed decrease in average field strength in the chromosphere. For example, if we assume that all the magnetic flux we observe in the photosphere passes through the level we observe in the chromosphere then the observed decrease in field strengths might be due to a channeling of the flux somewhat away from the 10830 Å features so that the field strength in those features is small.

Another explanation which we feel is more likely to be correct is simply that the magnetic field is more horizontal in the 10830 Å absorption features. This would reduce the observed line-of-sight field component and would be consistent with a spreading of the field with increasing height implied by the diffuseness of the 10830 Å fields.

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Discussion

Tandberg-Hanssen: Did you have Hα filtergrams of the same region where you saw dark features in 10830; and if so, what did the 10830 dark features correspond to?

Harvey: We did not have good Hα filtergrams corresponding to our 10830 observations. The comparisons we did indicate that the darkest features in 10830 are disk filaments in Hα. We intend to make simultaneous 10830 and Hα observations in the near future.