Magnetic fields in the upper chromosphere: He I 10830 Å as an almost ideal diagnostic

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Abstract

We develop the He I 10830 Å line as a quantitative diagnostic of upper chromospheric magnetic fields. An application to observations of an active region allows us to compare the magnetic field in the upper chromosphere and the underlying photosphere. In general the magnetic field in the chromophere is found to be significantly more homogeneous.

Magnetic fields dominate the structure and the energetics of the outer solar atmosphere, but in the vast majority of cases they are measured only in the photosphere. A number of diagnostics do exist for the measurement of chromospheric and coronal magnetic fields, but are affected by significant drawbacks.

In this paper we develop the He I 10830 Å line as a quantitative diagnostic of the magnetic field in the upper chromosphere. This line was pioneered as a qualitative magnetic diagnostic by Harvey and Hall (1971).

Some advantages of the He I 10830 Å line as a magnetic diagnostic are:

- The He I line can be observed from the ground with normal CCD's or other standard detectors, at a reasonable spatial resolution.
- It is formed entirely in the upper chromosphere (formation height 1600 to 2200 km) with no contribution at all from the photosphere, which greatly simplifies its interpretation.
- It is prominent over both sunspots and active region plages so that the magnetic field throughout active regions can be determined easily.
- The He I line is in general optically thin, or at the most marginally

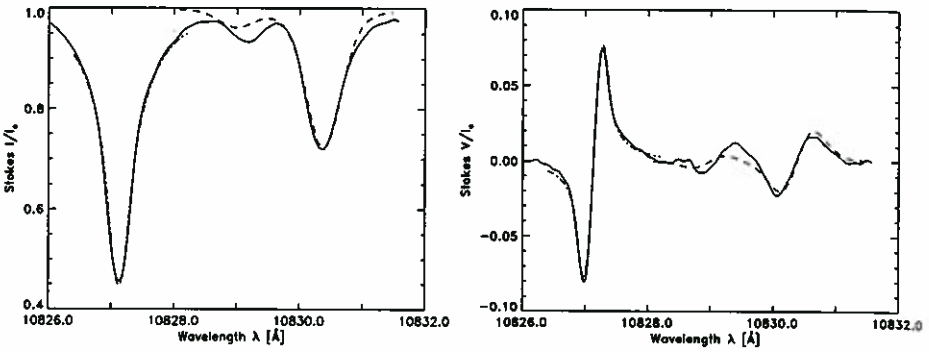

Figure 1: Measured (solid) and synthetic (dashed and dot-dashed) profiles of umbral Stokes I (upper panel) and Stokes V (lower panel).

optically thick, so that no complicated radiative transfer calculations need be carried out in order to measure the magnetic field.

- A photospheric Si I line is present in the nearby spectrum, allowing simultaneous and cospatial measurement of the photospheric magnetic field.

Stokes $I \pm V$ were recorded using the McMath telescope on Kitt Peak and the main spectrograph with the new infrared grating. Observations were carried out in an active region not too far from disc centre ($\mu = \cos\theta \approx 0.94$) and sampled different features such as plage, umbra, penumbra and superpenumbral canopy. A sample observation is shown in Fig. 1 (solid curves).

The method presented here rests on the fact that we are observing an optically thin line, which, due to its large non-magnetic width, is still in the weak-field regime. The longitudinal magnetic field strength averaged over a spatial resolution element, $\alpha B \cos\gamma$, is obtained from the observed Stokes I and V profiles:

$$V = 4.67 \times 10^{-13} g \lambda^2 B \cos\gamma \frac{dI}{d\lambda}. \qquad (1)$$

Figure 2 portrays the spatially averaged longitudinal field strength, $\alpha B \cos\gamma$, measured in both lines along a slice through the active region. Some results are summarized below:

- The magnetic field distribution at scales larger than $3''$ is considerably more homogeneous in the upper chromosphere than in the photosphere.
- In plages the magnetic flux through a surface element of $2-3''$ in size is equal in the photosphere and chromosphere.

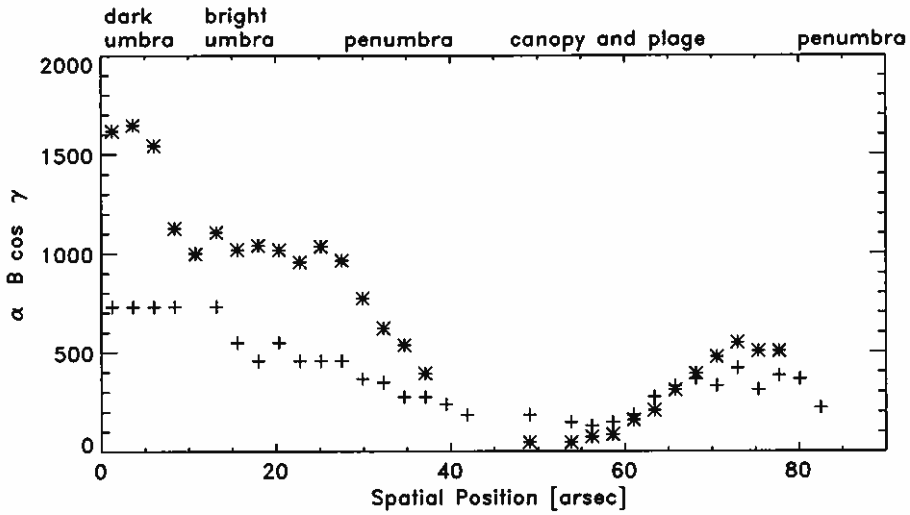

Figure 2: Longitudinal magnetic field as measured in the chromosphere (crosses) and in the photosphere (stars).

- The vertical magnetic field strength gradients we observe are 0.35-0.6 G/km in the umbra and 0.1-0.3 G/km in the outer penumbra.
- From a comparison with results published in the literature we conclude that the vertical magnetic gradient in sunspots decreases with height.
- The presence of an almost horizontal magnetic canopy in the upper photosphere near sunspots is confirmed by comparing the He I with the neighbouring Si I line.
- The present observations enabled us to measure chromospheric magnetic fields down to $\sim$ 100 G, but it should be possible to lower this limit to 50 G or less using observations with a lower noise level.

References

Harvey J.W., Hall D.N.B., 1971, in Howard, R. (ed.), 'Solar Magnetic Fields', Reidel, Dordrecht, *IAU Symp.***43**, 279