20^{th} *International Sacramento Peak Summer Workshop*
Advanced Solar Polarimetry - Theory, Observation, and Instrumentation
ASP Conference Series, Vol. 236, 2001
M. Sigwarth, ed.

Interpretation of the Large-Scale Solar Magnetic Field Measurements using the Line Ratio Technique

R. M. Veretsky, M. L. Demidov

Institute of Solar-Terrestrial Physics at the Siberian Division of the Russian Academy of Sciences, Irkutsk, P.O.Box 4026, Russia

Abstract. Measurements of the large-scale magnetic field strength, obtained with the magnetograph of the STOP telescope at the Sayan observatory, are interpreted in terms of a two-component model. Observations in the spectral lines of FeI 5247.1 Å, 5250.2 Å, 5250.6 Å and NiI 5137.1 Å are used. Theoretical magnetic field strength ratios for these lines are calculated. For this purpose, the Stokes-V parameters are derived by solving the radiative transfer equations for two flux tube models. By means of a comparison of experimental data and theoretical data, estimates of the "true" value of the magnetic field strength are obtained.

1. Introduction

According to present views regarding the structural properties of the solar magnetic field, most of the magnetic flux at the photospheric level is concentrated within so-called "flux tubes". The typical size of these fundamental components of the magnetic field is estimated at 100 - 200 km, which is at the resolution limit of ground-based solar telescopes. Flux tubes are directly observable with the help of sophisticated techniques such as speckle-polarimetry. However, there exist methods of indirectly estimating the values of flux tube parameters in solar observations with low spatial resolution. For investigating such a crucial characteristic of magnetic features as the magnetic field strength, the method of the strength ratio in spectral lines (MLR - Magnetic Line Ratio) was practiced widely (Stenflo 1973; Wiehr 1978; Stenflo & Harvey 1985; Solanki, Keller, & Stenflo 1987; Zayer et al. 1990; Solanki 1993). It is through the use of this method in magnetographic observations that it was, for the first time, confirmed that the magnetic flux on the Sun is concentrated within small unresolved elements (Frazier & Stenflo 1972; Howard & Stenflo 1972; Stenflo 1973). Currently magnetographic measurements are excelled by stokesmeter measurements which permit to measure Stokes parameter at high spatial and spectral resolutions (with instruments like ASP and ZIMPOL). Furthermore, it becomes possible to obtain the magnetic ratio "profile", thus extending the diagnostic capabilities of the method (Stenflo 1994).

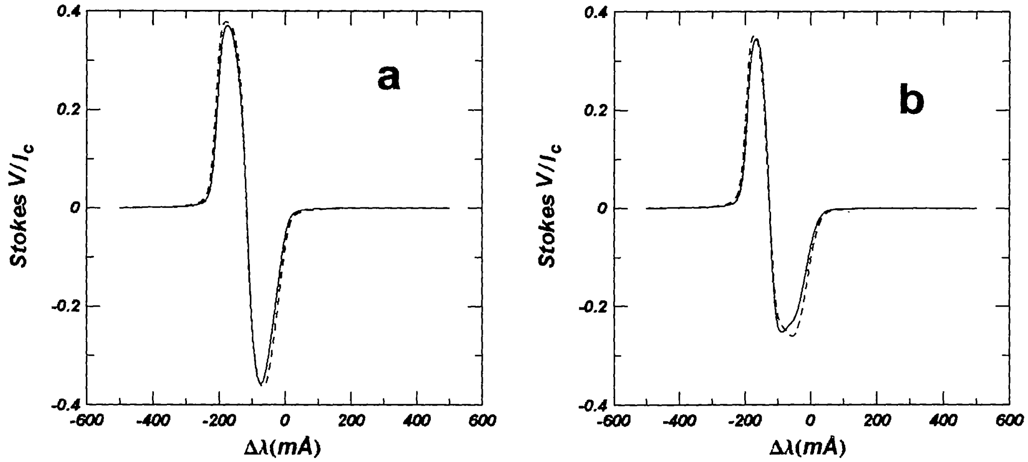


Figure 1. Results of numerical calculations of the Stokes V parameter for the line of FeI 5250.2 Å for the network (solid curve) and plage (dashed curve) models: **(a)** calculations with a homogeneous magnetic field ($B = 1200$ G) and with the line-of-sight velocity gradient; **(b)** calculations with the magnetic field and line-of-sight velocity gradients.

2. Method and Results

In this study we have applied the MLR method to the magnetic field observations with low spatial resolution ($\sim 2'$) from the STOP magnetograph at the Sayan observatory with the purpose of estimating the "true" values of magnetic field strengths in flux tubes. The magnetic field strength is estimated in terms of the widely used one-dimensional two-component model that assumes a magnetic and nonmagnetic component of the resolution element. This model is characterized by the following parameters: α - filling factor, B_{obs} - observed strength, and B_{true} - field strength of the magnetic component, with $B_{obs} = \alpha B_{true}$. A two-component model assumes that the differences in the strength of different regions of the solar photosphere are caused by a different density of magnetic elements in these regions. A justification for extensive use of just this model was reported in earlier papers (Frazier & Stenflo 1972; Frazier & Stenflo 1978). Besides, when interpreting results, it is assumed that the magnetic elements have a rectangular cross-section, i.e. the field strength at each particular level has a single value. This statement is supported by observations of the Zeeman line broadening in the infrared range (Zayer et al. 1989).

To bring the observed values of the strength ratio in different lines to the "true" value of B, it is necessary to perform a theoretical calculation of the Stokes-V parameter. To accomplish this, the equations of radiative transfer are solved in terms of a given model of the plane-parallel atmosphere using the LTE approximation for different values of the magnetic field strength. The differential equations are integrated by the Runge-Kutta method, and use is made of the asymptotic representation (Stepanov et al. 1975a) and stability properties of the solution (Stepanov et al. 1975b), as well as (Katz & Skochilov 1975). In the observations and calculations, we used the following lines: FeI 5250.2 Å and FeI 5247.1 Å, which are most common for investigations using the MLR method,

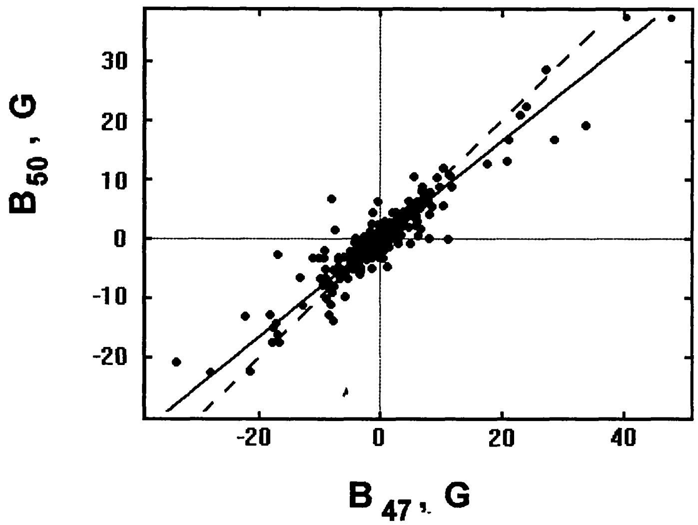


Figure 2. Comparison of the large-scale magnetic field measurements made at the STOP telescope of the Sayan Solar Observatory quasi-simultaneously in the line of FeI 5250.2 Å and FeI 5247.1 Å. The dashed and solid slant lines correspond to $\beta = 1$ and $\beta = 0.83$, respectively. The number of points N =4506.

as well as NiI 5137.1 Å and FeI 5250.6 Å. Two models of magnetic flux tubes, as suggested in (Solanki 1986), were used: the network model, and the plage model. Calculations were done with some simplifications such as: the Doppler is assumed to be constant with depth and the macroturbulent broadening is neglected. Figure 1a presents the calculated profiles of the Stokes-V parameter for the case of a homogeneous field with the strength of 1200 G and a line-of-sight velocity gradient in depth for the network model and for the plage model. Figure 1b shows the results of similar calculations, but for the case of the existence of both the magnetic field and line-of-sight velocity gradients.

An example of magnetographic observations used in this study is given in Fig. 2. The plot visualizes the result derived from comparing a large number (N=4506) of measurements (Demidov 1999) of the magnitude of the magnetic field in two lines: FeI 5250.2 AA and FeI 5247.1 Å. The slant line that is drawn through a cloud of points is a linear regression represented by the equation

$$B_{50} = 1.4(\pm 2.5) + 0.828(\pm 0.005) B_{47},$$

where B_{50} and B_{47} are the strengths measured in the lines of FeI 5250.2 Å and FeI 5247.1 Å, respectively. Hence the magnetic ratio in these lines is

$$\beta = \frac{B_{50}}{B_{47}} = 0.83.$$

An important point is that the comparison of the observations in these lines show a high correlation coefficient (~ 0.89). For comparison with these magnetographic measurements, the Stokes-V parameters, calculated in different lines, are integrated over the wavelength where the limits of integration are represented by the edges of the exit slits of the STOP magnetograph (the distances to the line center are 14 mÅ and 56 mÅ). The calculations assume a purely longitudinal and homogeneous (in depth) magnetic field for observations at the center of the solar disk. After that, by selecting the magnetic field strength, the value of the theoretical magnetic ratio was fitted to the observed ones. The estimated values of the magnetic field for the network and plage models are:

$$B_{network} \cong 1000\ G, B_{plage} \cong 1100\ G.$$

A similar analysis was also applied to the magnetographic measurements in the spectral lines of NiI 5137.1 Å and FeI 5250.6 Å. Figure 3 presents the theoretical calculations of the MLRs for different combination of spectral lines as a function of the magnetic field strength for the network and plage flux tube models. The observed magnetic ratios are presented in the second column in Table 1. The 3-rd and 4-th columns of this Table give the corresponding estimates of the "true" magnetic field strengths. B_t^N stands for the value of the magnetic field strength in the network model, and B_t^P corresponds to the plage model. The filling factor α ($\sim$ 0.5%-1%) for our observations of the large-scale magnetic field differs only slightly for the network and plage models.

Table 1. Results of estimating the "true" magnetic field strength.

	MLR	B_t^N	B_t^P
B_{47}/B_{37}	0.46	1900	2100
B_{50}/B_{37}	0.38	1200	1400
B_{50}/B_{51}	0.56	1000	1400
B_{47}/B_{51}	0.64	1700	2200

By analyzing the results of this investigation we noticed a significant scatter in the data of the magnetic field strength obtained by means of magnetic ratio in various magnetosensitive lines. This is not surprising, because among the used lines, only two (FeI 5247.1 Å and FeI 5250.6 Å) satisfy, to some extent, the magnetic ratio criterion. Some caution must be exercised as regards the conclusions drawn by using other lines, because in this case the difference of the formation depths of these lines, the thermal sensitivity, etc, are important. Moreover, the atmospheric and magnetic field models reflect rather crudely the actual situation, and results are strongly dependent on the assumptions underlying the model. Therefore the results should be regarded as a "first approximation" to the true picture. At the same time one may conclude that also in the case of large-scale magnetic field observations we can confidently apply a two-component model of the magnetic field and that powerful kilogauss fields can be distinguished in such observations.

To draw more accurate and more reliable conclusions requires further observations and improved models. Since 1999, the STOP magnetograph has been used as a stokesmeter instrument and extensive observational material has now been accumulated (Demidov et al., this proceedings). Using new data on Stokes

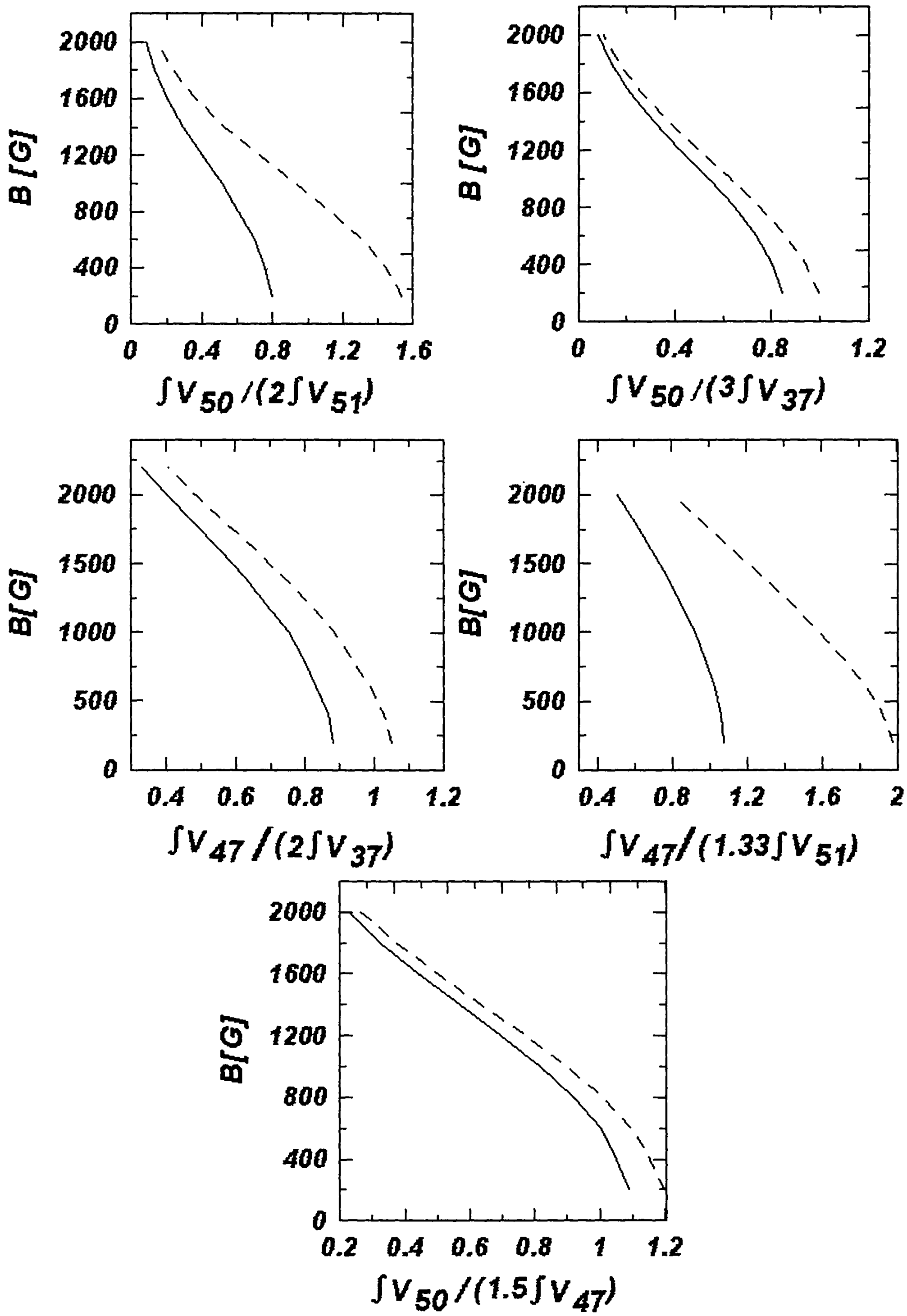


Figure 3. Calculated magnetic ratios versus magnetic field strength for the network (solid curves) and plage (dashed curves) models. Different combinations of spectral lines of FeI 5250.2 Å, 5247.1 Å, 5250.6 Å and NiI 5137.1 Å are used.

parameter profiles will make it possible to study subtle properties of the magnetic field elements, such as the fieldstrength, velocity and temperature gradients.

References

Demidov, M.L. 1999. JOSO Annual Report 1998, 87

Frazier, E. N., & Stenflo, J. O. 1972, Solar Phys., 27, 330

Frazier, E. N., & Stenflo, J. O. 1978, A&A, 70, 789

Howard, R., & Stenflo, J. O. 1972, Solar Phys., 22, 402

Katz, I. M., & Skochilov, V. G. 1975, Issled. Geomagn. Aeron. Fiz. Solntsa, 37, 93

Solanki, S. K. 1986, A&A, 168, 311

Solanki, S. K. 1993, Space Sci.Rev., 63, 1

Solanki, S. K., Keller, C., & Stenflo J. O. 1987, A&A, 188, 183

Stenflo, J. O. 1973, Solar Phys., 32, 41

Stenflo, J. O. 1994, Solar Magnetic Fields. Polarized Radiation Diagnostics. Kluwer Academic Publishers

Stenflo, J. O., & Harvey, J. W. 1985, Solar Phys., 95, 99

Stepanov, V. E., Grigoryev, V. M., & Katz, I. M. 1975a, DAN SSSR, 222, 1057

Stepanov, V. E., Grigoryev, V. M., & Katz, I. M. 1975b, DAN SSSR, 222, 1315

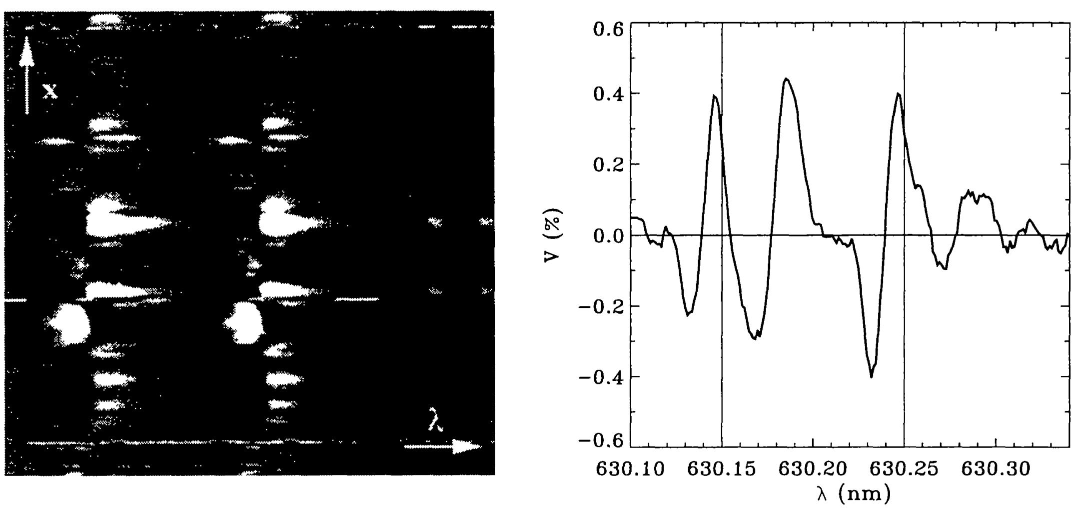
Wiehr, E. 1978, A&A, 69, 279

Zayer, I., Solanki, S. K., & Stenflo, J. O. 1989, A&A, 211, 463

Zayer, I., Solanki, S. K., Stenflo, J. O., & Keller, C.U. 1990, A&A, 239, 356

Part 7

Analysis of Stokes Profiles



Stokes-V spectrum of FeI 630.15 and FeI 630.25 measured in a young active region. Profiles with strong Doppler shifts and of unusual shape are visible. ASP data provided by M. Sigwarth.