MEASUREMENTS OF THE MAGNETIC FIELD AND THE GRADIENT OF TEMPERATURE IN THE SOLAR ATMOSPHERE ABOVE A FLOCCULUS USING RADIO OBSERVATIONS

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Abstract. Simultaneous observations made at several wavelengths in microwave range using the high spatial resolution of radiotelescope RATAN-600 make it possible to develop methods of measuring the magnetic fields in the solar corona and the chromosphere. In this paper we develop a method of measuring the magnetic fields from thermal bremsstrahlung and demonstrate it, using observations of a flocculus (plage) during August 1–3, 1977. The observations show that the flocculus under investigation possessed bipolar magnetic structure with peak to peak amplitude of magnetic field strength of about 40 G at the level of the upper chromosphere and the transition region (with a r.m.s. error of 5.7 G for favourable conditions). The radio astronomical map of the magnetic field is in agreement with the Mt. Wilson magnetic field map to within the experimental error. It follows that the average longitudinal magnetic field above the flocculus does not drop significantly with height above the photosphere up to the CCTR (chromosphere-corona transition region). An analysis of the spectra of polarized radio emission also gives an opportunity to determine the temperature gradient in the CCTR (which proved to amount to about 1000 K km$^{-1}$ and to follow their variation with height.

1. Introduction

At present the structure and development of the magnetic fields in the solar atmosphere are generally assumed to be the main factors ultimately responsible for all the phenomena of solar activity (see, for example, Kaplan et al., 1977; Stepanjan, 1976).

The field of a new active region emerges, in particular, at the border of a number of supergranules and is followed by a flocculus (plage) where sunspot and flare activity may develop later. Effective study of an active region essentially depends on a variety of methods used for magnetic field measurements. This is the reason why the interest of solar astrophysicists is permanently focussed on the methods of investigations of magnetic fields (Stenflo, 1978).

Optical magnetographs based on Zeeman splitting of spectral lines yield the most comprehensive and reliable data on magnetic fields at the photospheric level. Using the chromospheric lines, however, does not provide a similar level of information. On the other hand, it is just in the chromosphere that microwave radiation originates.
Big instruments intended for the investigation of solar radio emission and its polarization give an opportunity to develop methods of magnetic field measurements (weak field included) of different solar features in the chromosphere and upper levels of the solar atmosphere.

Radio emission of the quiet Sun and flocculi are well accounted for in terms of thermal bremsstrahlung (see, for example, Zheleznyakov, 1964). In the presence of a magnetic field this emission becomes circularly polarized due to the differences in absorption for ordinary and extraordinary modes of magneto-ionic theory. The interpretation of polarization measurements as thermal bremsstrahlung of the Sun allows us, in principle, to measure the strength of the magnetic field. As was shown by Gelfreikh (1972), modern radioastronomical observations may yield an accuracy of \( \approx 1 \) G, which is comparable with the accuracy of optical magnetographs.

This paper deals with some provisional measurements of weak magnetic fields of a flocculus using the radiotelescope RATAN-600 (Berlin et al., 1977).

2. Theory

The degree of circular polarization of thermal bremsstrahlung is given by

\[
P = \frac{(T_{Be} - T_{Bo})}{(T_{Be} + T_{Bo})},
\]

where \( T_{Be}, T_{Bo} \) are brightness temperatures for extraordinary and ordinary modes respectively (their expressions are considered below). Here the limiting polarization (see Zheleznyakov, 1977) is assumed to be circular. The brightness temperature is determined by

\[
T_B(f, f_H, \alpha) = \int_0^\infty T(l) \exp \left[ -\tau_j(f, f_H, \alpha, l) \right] d\tau(l, f_H, \alpha),
\]

where

\[
\tau_j = \int_0^l \kappa \, dl'
\]

and

\[
\tau_j(l, f_H, \alpha) = \int_0^l \kappa_j[N(l), T(l), f_H(l), \alpha(l)] \, dl'.
\]

\( N(l) \) and \( T(l) \) are the distributions of electron density and temperature along the line of sight. The parameters of the magnetic field, the gyrofrequency \( f_H \) and the angle \( \alpha \) between the magnetic vector and the line of sight, also can vary along the line of sight. These values, however, are considered here as constants (homogeneous field). The indexes \( j = e \) and \( o \) refer to the extraordinary and ordinary modes respectively.