ACTIVE REGION MAGNETIC FIELDS AND cm-λ EMISSION

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ABSTRACT- The influence of the magnetic field on the structure of sunspot-associated sources at cm-λ has been investigated through model calculations. The case of a source observed with the Westerbork SRT and the structure of a single sunspot source are considered.

1. INTRODUCTION

High resolution observations of solar active regions at cm-λ (Kundu et al, 1977; Pallavicini et al, 1979; papers presented in this Symposium by Velusamy and Kundu, Lang and Willson, Pallavicini) have shown the close relationship between the cm emission and the magnetic field structure of the regions. The cm-λ observations are, so far, the only ones capable of giving direct information on the magnetic field in the transition region (T.R.) and the low corona. Thus, model computations are important for diagnosing the physical conditions and understanding the physical processes in this part of the solar atmosphere. This paper presents a summary of our efforts to interprete some of the details in the observed structure of sunspot-associated components and to point out observable features for future high resolution observations.

2. INTERPRETATION OF HIGH RESOLUTION OBSERVATIONS

In this section we discuss the interpretation of one sunspot-associated source observed on May 9, 1974 with the Westerbork SRT (resolution 6" by 22"). The interpretation was done in terms of simple, plane-parallel models of the electron temperature and density, using photospheric magnetic fields observed by Rayrole at Meudon (Alissandrakis et al, 1979).

The main contributor to the sunspot-associated emission is the gyroresonance (g-r) process (Zheleznyakov, 1962; Kakinuma and Swarup, 1962). There is also some contribution from the free-free process. The model adopted for the change of temperature with height was one with constant conductive flux, while the density was determined by hydrostatic equili-

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brium. The magnetic field was extrapolated under the current-free (potential) assumption. The transfer equation was integrated numerically to give two-dimensional maps of total intensity (I) and circular polarisation (V). These were convolved with the WSRT beam and compared with the observations. In the best fit model all the observed features were satisfactorily reproduced, assuming a conductive flux of 2 10^6 erg cm^{-2} s^{-1}, an electron pressure of 10^{15} at the base of the T.R., which was assumed to be 2 10^8 cm above the photosphere. The intensity of the magnetic field had to be increased by a factor of 2.15 above the value given by the current-free computation. For the interpretation of the cm emission it is necessary to have the second and third harmonics of the gyrofrequency at high temperature (about 10^6 K), which immediately implies magnetic fields of 900-600 G in the region of formation of the radiation.

3. COMPUTATION OF THE EMISSION FROM A SINGLE SUNSPOT

After the interpretation of the WSRT observations it was considered worthwhile to compute maps of sunspot regions at various heliocentric distances, θ and at various wavelengths. Such computations will be useful in connection with the upcoming VLA observations. Similar computations have been done by Zlotnik (1968) for a source located at the center of the disk. The temperature and density models were the same as above, while the magnetic field was approximated by a dipole, vertical to the solar surface, located 2 10^9 cm below the photosphere. At the photosphere the FWHM of the model spot was 4 10^9 cm and the field strength was 2000 G. Two-dimensional maps of the ordinary and extraordinary radiation, as well as of I and V were computed at 2.7, 4.0, 6.0, 9.0 and 13.5 cm for heliocentric distances of 0, 15, 30, 45, 60 and 75°.

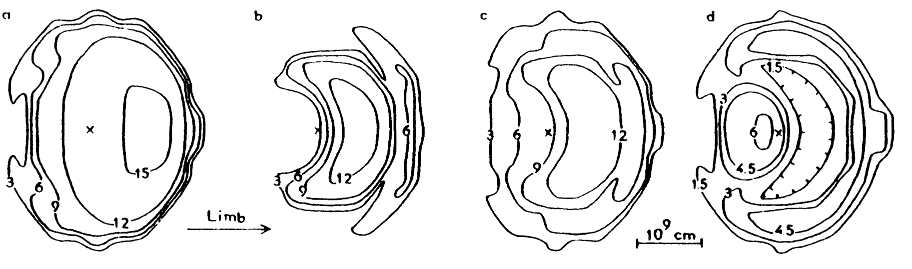

Figure 1. Maps of a sunspot-associated source 30° from the center of the disk at 6 cm; a:ordinary, b:extraord., c:I, d:V. Labels are in 10^5 K.

In general the first three harmonics of the gyrofrequency contribute to the emission provided that they are located in regions of high temperature. At sufficiently high θ the fourth harmonic contributes as well. Extraordinary emission from the fundamental is below the reflection level, while ordinary emission may escape if the overlying second harmonic is optically thin. The angle between the magnetic field and the line of sight is very important since g-r opacity increases very rapidly with it. Figure 1 shows computed maps at 6 cm for θ=30°. Here the third harmonic

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dominates the extraordinary emission almost over the entire source, while only the limbward parts of the third and second harmonics are opaque in ordinary radiation. Hence the structure of the ordinary map, with two crescent-shaped sources due to third (in the direction of the limb) and second harmonic emission. The V map shows a shell structure, since the source is larger in extraordinary radiation than in ordinary. The crescent structures are more obvious at shorter wavelengths and at larger heliocentric distances. In general the sources are flat-topped and show a fast drop of brightness temperature in the direction of the limb. The I source is displaced towards the limb more than the V source.

Some integrated properties of the sources were also computed, which will be useful in comparisons with medium resolution observations; these include the source flux, position and size as functions of λ and θ. In particular the I and V flux show the well known maxima, but the wavelength of maximum flux depends on θ; the maximum occurs at shorter wavelengths for large θ. The center-to-limb variation of the flux is almost cosine-shaped at long λ, while at shorter wavelengths it becomes flat near the center of the disk, in agreement with the observations of Lubyshev (1977). At even shorter wavelengths the flux has a maximum around θ=45°.

4. CONCLUSIONS

Model computations have shown that the appearence of sunspot-associated sources at cm-λ as well as their integrated properties depend greatly on the magnetic field. From the source shape one can determine which harmonics are responsible for the emission and from this one can get immediately the intensity of the magnetic field. Observations at different wavelengths will permit the study of the magnetic field as a function of temperature and, inderectly, as a function of height. Some information can be obtained even from medium resolution observations of the flux, position and size of the sources at various wavelengths and heliocentric distances.

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DISCUSSION

Schmahl: I think it is remarkable to find such good agreement between the model and the observations, in view of the (perhaps) unrealistic density and temperature profile. This may suggest that the magnetic field configuration dominates other parameters.

What exactly was the height in your model at which the temperature of 1 x 10^6 K was reached?

Alissandrakis: Indeed the gyroresonance absorption coefficient depends strongly on the intensity of the magnetic field (which determines the harmonic number), and the angle between the field and the line of sight, while it has a weaker dependence on temperature and density. In the best-fit model the temperature of 10^6 K is reached at a height of approximately 5000 Km.

Drago: Observations made 2 months later at Westerbork by Felli, Tofani and myself at 21 cm-λ do not show any polarization above active regions. A strong circular polarization of opposite sense is found instead at the two sides of a large filament where the brightness temperature is very low. The interpretation is that above active region both the ordinary and extraordinary optical depth reaches high values in the corona and therefore T_b is higher and P is low. In the other regions we have $\tau_x > \tau_o$ and both lower than 1. So that is: T_b low and P high.

Alissandrakis: At 21 cm the free-free process dominates over gyroresonance and hence the low circular polarization that you observed above the active regions. At 6 cm and for the source studied here, the observed polarization is about 30%; moreover the computations showed regions that were almost 100% polarized but these regions are smoothed by the finite instrumental resolution.

Pallavicini: You mentioned that the gyroresonance interpretation of the sunspot-associated radio sources requires a magnetic field at coronal levels which is higher by about a factor of 2 than the value obtained on the basis of an extrapolation of the photospheric magnetic field to coronal levels in the current-free approximation. Did you take into account possible saturation effects in the magnetic field measurements from Meudon?

Alissandrakis: The magnetic field is determined by measuring the displacement of the Zeeman components of the λ 5225 FeI line, rather than the intensity difference at two fixed wavelengths; thus saturation at high field values is avoided. I think that the factor of two is, most likely, due to deviations from the potential field.