Proceedings of the Research Institute of Atmospherics,
Nagoya University, vol. 32(1985)

RESEARCH REPORT

SPECTRUM S-COMPONENT FLUX AND ACTIVE REGION MAGNETIC FIELD

Kiyoto SHIBASAKI

Abstract

Characteristics are examined of an active region magnetic field structure whose spectral peak of S-component source flux is of a higher frequency than that of normal source. The flux ratio at 3 cm and 8 cm wavelengths (F3/F8) is used as an indicator of peak frequency. The magnetic field structure of an active region with a high flux ratio is compared with a structure with a low flux ratio. It is shown that low-lying magnetic lines of force are characteristic of active regions with high flux ratio. High temperature and high density plasma confined by low-lying magnetic lines of force intensify the flux at short wavelengths, thus the flux peak shift to a shorter wavelength.

1. Introduction

Radio emission associated with solar active regions is designated the S-component. Usually the frequency spectrum of S-components has a peak around 3 GHz. In some acive regions, however, the peak occurs at higher frequencies. Statistical studies (Tanaka and Kakinuma, 1964; Tanaka and Enome, 1975) show that these active regions have a high probability of producing proton flares.

To determine the frequency spectrum of S-components, Observations at several frequencies are required. However, there are only two sets of interferometers at Toyokawa observatory. One is at 3.75 GHz and the other is 9.4 GHz. Therefore the flux ratio of S-component sources at these two frequencies are used as an indicator of peak frequency of the spectrum. In normal S-components, 3.75 GHz is close to the peak frequency and 9.4 GHz is far above it; the flux ratios of these sources are small. On the other hand, in those S-component sources whose peak frequency is higher, the flux at 3.75 GHz is smaller and the flux at 9.4 GHz is larger than that of normal sources, resulting in high flux ratio.

Two different emission mechanisms contribute to the S-component; one is free-free (f-f) emission, the other gyro-resonance (g-r) emission. Around the spectral peak frequency, g-r emission is the main contributor. A strong magnetic field is necessary for g-r emission to dominate f-f emission (Kakinuma and Swarup, 1962). For a simple sunspot, the calculated intensity distributions using model sunspot are in agreement with the observed intensity distribution (e.g. Allisandrakis, 1980; Shibasaki et al., 1983). For a complex active region, measurement of the actual distibution of a magnetic field is necessary to calculate the structure and thickness of resonance layers.

In the following sections, active regions with high flux ratio were selected and characteristics of magnetic field structures were studied by comparison with normal S-component sources.

2. S-component observation and magnetic field data

There are two sets of radio interferometers at Toyokawa observatory (Tanaka et al., 1970; Ishiguro et al., 1975). Observing frequencies are 9.4 GHz and 3.75 GHz. They operate in both two-dimensional and one-dimensional modes. The data of the one-dimensional mode is used because of higher angular resolution and more stable operation. The one-dimensional angular resolution of both interferometers is 1.1 arc min. at local noon. Observations are done about 4 hours per day. For the S-component source flux, one E-W drift scan curve obtained every day at local noon is used at each frequency. Each one-dimensional profile is normalized by the total flux observed at the same time and frequency. The quiet sun distribution is obtained by connecting the most probable lowest values in each 27-day data bin.

After subtracting the quiet sun distribution, the flux is calculated for each S-component source by integrating the one-dimensional distribution. Thus we get one flux ratio (F3/F8) per day for each S-component source. From the listing of the flux ratios, we selected several sources whose flux ratio is close to or greater than one.

The observation of solar magnetic field was begun in 1982 at Okayama Astrophysical Observatory of Tokyo Astronomical Observatory (Makita et al., 1985). Digital data of the photospheric magnetic field has been available since December 1982. Most of the data is published in "Vector Magnetograms of Solar Active Regions (December 1982 - December 1983)". The active region AR4173, whose S-component source has high flux ratio was selected from this reference. For comparison, AR4183 was selected; the flux ratio of the associated S-component source is smaller, and the active region scale size and the magnetic field strength are similar to AR4173.

3. Characteristics of an active region with high flux ratio

Figure 1 shows one-dimensional intensity profiles of the S-components associated with AR4173 and AR4183 at both 3 cm (9.4GHz) and 8 cm (3.75GHz). The quiet sun profiles has already been subtracted from each scan. The intensity scale is the same for profiles of 3 cm and 8 cm. This figure indicates that the flux ratio (F3/F8) of AR4173 is approximately 1.0 and that of AR4183 is less than 0.5.

The photospheric magnetic fields of AR4173 and AR4183 are shown in Figure 2. The area of observation is 8 arc min. in the E-W direction and 7 arc min. in the N-S direction. Thin solid contours indicate north polarity and dotted contours indicate south polarity. Contour levels are 10, 20, 50, 100, 200, 500, and 1000 gauss for both north and south polarity. Sunspot sketches (Mitaka, Tokyo Astronomical Observatory) are superimposed by thick solid curves. This figure shows that two umbrae of opposite polarity are located in a single penumbra in the following section of AR4173. The preceding section of AR4183 is of similar size and structure as that of AR4173, but the following part consists of scattered small sunspots.

Magnetic lines of force above the active regions are shown in Figure 3. They are calculated using the longitudinal component of photospheric magnetic fields assuming potential magnetic fields

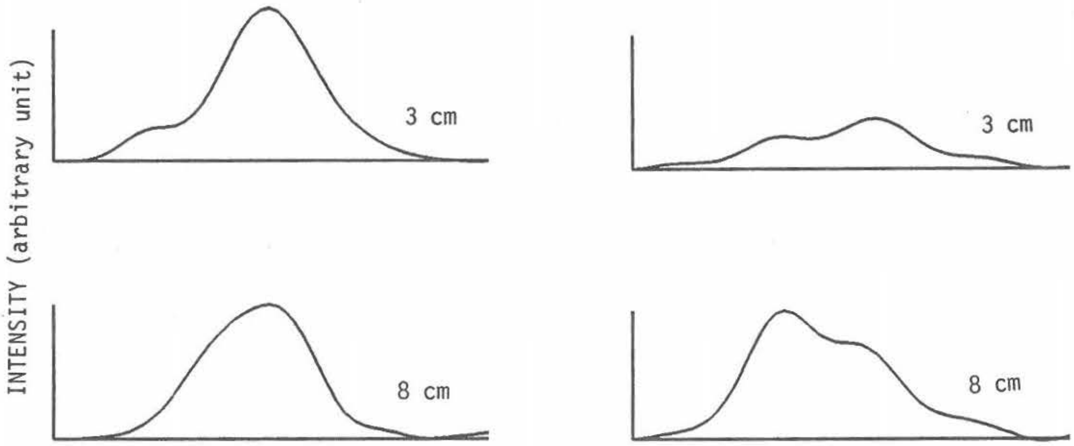


Fig. 1. One-dimensional intensity profiles of S-component sources associated with AR4173 (left) and AR4183 (right). East is to the left and West is to the right. The quiet sun has already been subtracted from each distribution. East-West span is 8 arc min.

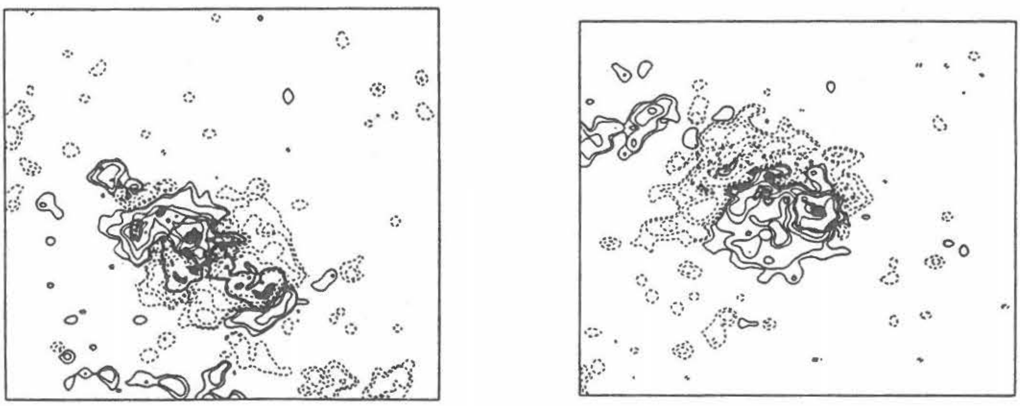
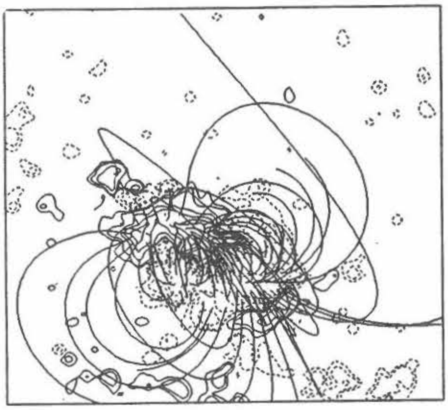


Fig. 2. Photospheric magnetic field and sunspots of AR4173 (left) and AR4183 (right). Celestial North is to the top and East is to the left. Field of view is 8 arc min. (EW) by 7 arc min. (NS). Thin solid coutours are north polarity and dotted contours are south polarity. Contour levels are 10, 20, 50, 100, 200, 500, and 1000 gauss. Thick solid curves are sunspots.



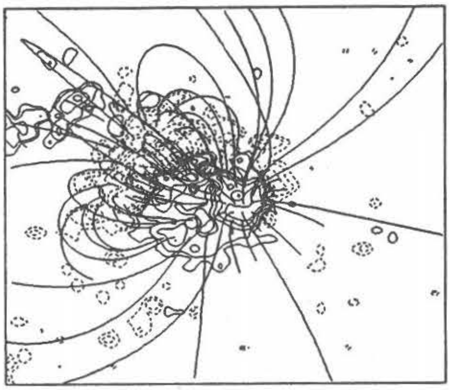


Fig. 3. Magnetic lines of force and photospheric magnetic field of AR4173 (left) and AR4183 (right). Others are same as Fig. 2.

(Sakurai, 1981). The striking difference between the magnetic lines of force of AR4173 and those of AR4183 is the low-lying closed magnetic lines of force in AR4173. They connect the strong magnetic field of sunspots close to each other. In AR4183, on the other hand, most of magnetic lines of force from the large sunspot diverge or form tall loops.

4. Interpretation

Emission mechanisms of S-component are f-f and g-r emission. In active regions which have strong magnetic fields, g-r emission dominates f-f emission. The flux of g-r emission is determined by several parameters: optical depth of the resonance layer (which depends on density, temperature, magnetic scale height, and angles between line of sight and magnetic lines of force), temperature, and the area of the resonance layer. At shorter wavelengths, the magnetic field strength of the resonance layer must be strong. For example, the isogauss surface of 400 gauss corresponds to the third harmonic layer at 8 cm, while the corresponding harmonic layer at 3 cm is a 1000-gauss isogauss layer. At coronal temperature, the optical depth of higher order resonance layers is so much smaller than that of the third order that it does not contribute to the flux. Thus, one of the necessary conditions for large flux at 3 cm is a strong magnetic field. Observationally, there is a large difference in 3 cm flux between AR4173 and AR4183, even though these two active regions have similar magnetic field strengths at the photosphere and active region areas. It was shown in the previous section that a main difference between AR4173 and AR4183 is the low-lying closed magnetic lines of force found in the former. The relation of these lines of force to large flux at 3 cm can be explained in the following way: The resonace layer at 3 cm is located at a very low altitude, and the lines of force penetrating the resonance layer are closed within the active region. Presumably, these lines of force confine high density and high temperature plasma. Hence, we can consider that the resonance layer becomes optically thick and the flux at 3 cm increases due to the high temperature. For example, if we take a typical electron density of 5 X 10^9 cm (Dere and Mason, 1981) at 2 X 10^6 K and a magnetic scale height of 2 X 10^9 cm, the optical depth of the extraordinary mode at the third harmonic layer exceeds one when the angle between the line of sight and the magnetic line of force is larger than 35 degrees. On the other hand, magnetic lines of force penetrating the resonance layer of 8 cm are not influenced by low-lying magnetic lines of force because the resonance layer at 8 cm is situated at a high altitude.

5. Discussion

Several model calculations have been done of the spectrum of S-components (e.g. Gel'freikh and Lubyshev, 1979). Jin-Xing (1982) studied the flux ratio (F3/F8) of an S-component source associated with a large active region in August 1972. Dipole magnetic configuration is assumed for calculation and several parameters are introduced to fit the observed spectrum and flux. If several parameters are employed to explain the large flux at 3 cm, the flux ratio becomes too large. To make the flux ratio close to one, a magnetic field of small scale height and thin optical depth are needed. This conclusion depends very much on models of magnetic field parameters. A very small magnetic scale height is artificially introduced to fit the observed flux ratio, one order of magnitude smaller than that of the model magnetic field which was used by the author.

In the model calculation above, it was assumed that temperature and density depend only on height. But observation (e.g. Webb, 1981) shows that the active regions consist of many loop structures. Our study suggests that a more realistic density and temperature model is necessary to explain the high flux ratio of the S-component source.

The magnetic field and S-component of AR4173 were observed on May 12, 1983. This active region developed very quickly between May 10 and May 11 and produced several flares. A weak proton enhancement was associated with a large flare on May 15. The flux ratio was large from May 11 until May 16 when it crossed the west limb. On the other hand, the activity of AR4183 decreased suddenly between May 21 and May 22, while observations of the S-component and magnetic field were made on May 22. Only very weak activities were associated with AR4183 and the flux ratio was small even before May 22. No proton enhancement associated with the flares of AR4183 was reported. In these two active regions, the high flux ratio is related to the growing phase of the active region, while the low flux ratio is related to the declining phase of the active region.

Potential field approximation is used in the calculation of magnetic field. In general, magnetic lines of force are deformed by current in the atmosphere of the active region. But the low-lying magnetic lines of force are not deformed to a significant degree by the current because the sunspot magnetic field is strong. So the potential assumption is sufficient for the calculation of magnetic lines of force at low altitude.

In the preceding sections, characteristics of an active region where the flux ratio of the S-component source is large (AR4173) were described by comparison with a region where the S-component source has a small flux ratio (AR4183). More observation is required to generalize the results give here. The study of the relation between the proton event and an S-component source with high flux ratio will be the next step of this study.

Acknowledgments

Magnetic field data and sunspot sketches were kindly supplied by the Tokyo Astronomical Observatory. The author wishes to thank Dr. Sakurai for supplying computer programs by which potential magnetic lines of force were calculated and magnetic field data were displayed.

This research was supported by a Grant-in-Aid for Scientific

Research (59540139) and a Grant-in-Aid for Co-operative Research (59340012) of the Ministry of Education, Science and Culture.

References

Alissandrakis, C.E.: Active region magnetic field and cm- λ emission, Solar Physics of the Sun, D. Reidel Publ. Co., ed. by M.R. Kundu and T.E. Gergely, 101-104(1980).

Dere, K.P. and H. Mason: Spectroscopic diagnostics of the active region: Transition zone and corona, Solar Active Regions, Colorado Associated Univ. Press, ed. by F.Q. Orrall, 129-164(1981).

Makita, M., S. Hamana, K. Nishi, M. Shimizu, H. Koyano, T. Sakurai, and H. Komatsu: Observations by the solar vector magnetograph of the Okayama Astrophysical Observatory, Publ. Astron. Soc. Japan in press.

Gel'freikh G.B. and B.I. Lubyshev: Structure of local sources of the S component of solar radio emission, Sov. Astron. 23, 316-322(1979).

Ishiguro, M., H. Tanaka, S. Enome, C. Torii, Y. Tsukiji, S. Kobayashi, and N. Yoshimi: 8-cm Radioheliograph, Proc. Res. Inst. Atmospherics, Nagoya Univ. 22, 1-25(1975).

Jin-Xing, Y.: Spectral character of solar radio SVC in solar proton active region, Acta Astron. Sinica 23, 309-316(1982).

Kakinuma, T. and G. Swarup: A model for the sources of the slowly varying component of microwave solar radiation, Astrophys. J. 136, 975-994(1962).

Sakurai. T.: Green's function methods for potential magnetic fields, Solar Phys. 76, 301-321(1981).

Shibasaki, K., F. Chiuderi-Drago, M. Melozzi, C. Slottje, and E. Antonucci: Microwave, ultraviolet, and soft X-ray observations of Hale Region 16898, Solar Phys. 89, 303-321(1983).

Tanaka, H. and T. Kakinuma: The relation between the spectrum of slowly varying component of solar radio emission and solar proton event, Rep. Ionosphe. Res. Japan 18, 32-44(1964).

Tanaka, H., S. Enome, C. Torii, Y. Tsukiji, S. Kobayashi, M. Ishiguro, and M. Arisawa: 3-cm Radioheliograph, Proc. Res. Inst. Atmospherics, Nagoya Univ., 17, 57-74(1970).

Tanaka, H. and S. Enome: The microwave structure of coronal condensations and its relation to proton flares, Solar Phys. 40, 123-131(1975).

Webb, D.F.: Active region structures in the transition region and corona, Solar Active Regions, Colorado Associated Univ. Press, ed. by F.Q. Orrall, 165-198(1981).