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SOLAR RADIO S-COMPONENT VARIATION WITH THE MAGNETIC FIELD OF ACTIVE REGIONS

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ABSTRACT According to an active region model proposed in the present paper, i.e. three-dimensional and continuous distributions of the three plasma parameters (electron temperature, electron density, and magnetic field) from the active region to the quiet region, and using the combined mechanisms of gyroresonance radiation and bremsstrahlung, we have researched the solar radio S-component (i.e. the slowly varying component or SVC) variation with the magnetic field of active regions.

INTRODUCTION

In the present paper, by adopting continuously varying electron temperature and density, a basic magnetic dipole field model, and using the combined mechanisms of gyroresonance and bremsstrahlung radiation, we have calculated the SVC radiation at 15 wavelengths for 8 magnetic field distributions, and studied the main SVC radiation characteristics (such as the spectra of flux density, polarization degree, brightness temperature, and the brightness distribution) and the geometrical features of the SVC radiation source (such as the height and the radius), and their variations with the magnetic field. Some significant results have been obtained.

MODEL OF ACTIVE REGION WITH CONTINUOUSLY VARYING PHYSICAL PARAMETERS

According to electrodynamics, the magnetic dipole field can be expressed by

$$B(r,h) = \frac{[r^2 + 4(h+d_0)^2]^{1/2}}{2[r^2 + (h+d_0)^2]^2} d_0^3 B_0, \tag{1}$$

and the angle between the field and the radiative direction can be written as

$$\alpha(r,h) = \arctan \frac{3r(h+d_0)}{2(h+d_0)^2 - r^2}, \tag{2}$$

where r is the distance from the central axis of the active region, h the height above the photosphere, and B_0 the magnetic field strength at the photospheric level. The characteristic scale-height for the variation of the field is

$$L_B = \frac{B}{|\partial B/\partial h|}. \tag{3}$$

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The electron temperature and density in the chromosphere-corona transition region can be given by (Zhao 1991a)

$$T(r,h) = [3.5 \times 10^{12} \mu(r)(h - h_0) + T_0^{7/2}]^{2/7} \quad \text{(c.g.s.)} \tag{4}$$

and

$$N(r,h) = \frac{N_0 T_0}{T} \exp[-6.6 \times 10^{-17} \frac{1}{\mu(r)} (T^{5/2} - T_0^{5/2})] \quad \text{(c.g.s.),} \tag{5}$$

respectively, where T_0 and N_0 are the electron temperature and density at the base, whose height is h_0, of the transition region, respectively, and $\mu(r)$ is the coefficient of conductive flux.

As for the electron temperature and density in corona, we assume that T very slowly decreases with h above a maximum value of $2 \times 10^6 \mu(r)^{2/7}$:

$$T(r,h) = 2 \times 10^6 \mu(r)^{2/7} (1 + 1.4368 \times 10^{-11} h)^{-3} \quad \text{(c.g.s.).} \tag{6}$$

From the corresponding height upward, $N(r,h)$ becomes:

$$N(r,h) = 7.272 \times 10^{17} \mu(r) h^{-0.9978} \quad \text{(c.g.s.).} \tag{7}$$

The electron temperature and density in the chromosphere can be written, respectively, as follows (Zhao 1991a):

$$T(h) = C_1 + C_2 h \tag{8}$$

and

$$N(r,h) = C_3 \mu(r) \exp(C_4 h), \tag{9}$$

where C_1, C_2, C_3, and C_4 depend on the range of h.

MODEL OF S-COMPONENT SOURCES

Using the model of the magnetic field, the geometrical configurations of the gyroresonance layers can be obtained from

$$\frac{[r^2 + 4(h + d_0)^2]^{1/2}}{[r^2 + (h + d_0)^2]^2} \approx \frac{4\pi mc^2}{s\lambda e d_0^3 B_0} \quad \text{(c.g.s.e.).} \tag{10}$$

The parameters in equation (10) are defined in the referenced papers.

Finally, according to the characteristics of the S-component radiation, the height of the S-component source, h_{sou}, can be estimated (Zhao 1991a,c)

$$h_{sou} \approx d_0 [\frac{(\lambda B_0)^{1/3}}{15.2834} - 1], \tag{11}$$

and the radius of the source, r_{sou}, can be determined by

$$\frac{[r_{sou}^2 + 4(h_0 + d_0)^2]^{1/2}}{[r_{sou}^2 + (h_0 + d_0)^2]^2} \approx \frac{7139.89}{\lambda d_0^3 B_0}, \tag{12}$$

where h_{sou}, r_{sou} and d_0 are in units of 10^4 km.

It can be seen that both the height and radius of the S-component source increase with increasing magnetic field and/or wavelength.

COMBINED MECHANISM OF GYRORESONANCE RADIATION AND BREMSSTRAHLUNG

The radiation intensity generated from the combined mechanism of gyroresonance radiation and bremsstrahlung can be written as

$$T_{b,j}^{com} = \int_0^{\tau_{0,j}} T \exp(-\tau_{j,s}^{g-r} - \tau_j^{f-f}) d\tau_{j,s}^{g-r} + \int_0^{\tau_{0,j}} T \exp(-\tau_{j,s}^{g-r} - \tau_j^{f-f}) d\tau_j^{f-f}. \tag{13}$$

The optical depth, $\tau_{j,s}^{g-r}$ (in c.g.s.e.), of the gyroresonance process can be expressed as follows (Zhao 1991b) :

$$\tau_{2,1}^{g-r} = \frac{2\pi e^2 k}{(mc^2)^2} T_1 N_1 L_{B_1} \lambda F(\alpha_1), \tag{14}$$

and

$$\tau_{j,s\geq 2}^{g-r} = \frac{s^{2s}}{2^s s!} \frac{\pi e^2 k^{s-1}}{(mc^2)^s} T_s^{s-1} N_s L_{B_s} \lambda F_j(s, \alpha_s). \tag{15}$$

The absorption coefficient, η_j^{f-f} (in c.g.s.e.), of the $f-f$ process is (Zhao 1991b)

$$\eta_j^{f-f} = 4(\frac{2}{\pi})^{1/2} \frac{e^6}{c^3 (mk)^{3/2}} \frac{Q\lambda^2 N^2}{T^{3/2}} G_j(v, u, \alpha). \tag{16}$$

Subtracting the contribution from the quiet Sun, $T_{b,QS}$, from the $T_{b,j}^{com}$, the brightness temperature of the net SVC radiation is given by

$$T_{b,j}^{net} = T_{b,j}^{com} - T_{b,QS}. \tag{17}$$

For the radiation of the whole SVC source having a radius of r_{sou}, the total brightness temperature of the SVC emission can be written as

$$T_{b,j}^{tot} = \frac{\int_0^{r_{sou}} T_{b,j}^{net}(r) r dr}{\int_0^{r_{sou}} r dr}. \tag{18}$$

Therefore, the total flux density of the SVC emission has the following form:

$$S_j^{tot} = \int_{\Omega_s} \frac{k T_{b,j}^{tot}}{\lambda^2} d\Omega = \frac{2\pi k}{D_{S-E}^2 \lambda^2} \int_0^{r_{sou}} T_{b,j}^{tot}(r) r dr, \tag{19}$$

and

$$S^{tot} = \int_{\Omega_s} \frac{2k T_b^{tot}}{\lambda^2} d\Omega = S_1^{tot} + S_2^{tot}. \tag{20}$$

The total polarization degree of the SVC emission can be obtained from

$$P^{tot} = (T_{b,1}^{tot} - T_{b,2}^{tot})/(T_{b,1}^{tot} + T_{b,2}^{tot}). \tag{21}$$

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SUMMARY AND CONCLUSIONS

We have computed the SVC at 15 wavelengths (λ from 1 to 50 cm) for 8 magnetic field distributions (B_0 from 500 to 4000 Gauss) for an active region. The following results have been obtained from these calculations:

(1) The total SVC radiation increases with increasing magnetic field and wavelength.

(2) The SVC brightness distribution shows that there is a bright region with stronger radiation in the central part of the SVC source in the centimetric waveband and a uniform radiation distribution along the source in the decimetric waveband. Moreover, the bright region strengthens and expands with increasing magnetic field.

(3) The spectrum of the SVC brightness temperature rises with increasing magnetic field. The brightness temperature monotonically increases with increasing wavelength.

(4) The most important feature of the SVC radiation is the spectrum of flux density. The spectral shape varies with the magnetic field. Moreover, there is an evident spectral peak, which moves towards higher frequency and increases as the magnetic field increases. The peak position is in the wavelength range of 4 - 10 cm. Especially, the "spectral valley" of the SVC radiation, which is a new characteristic, has been theoretically discovered in the present paper.

(5) There is an obvious spectral peak in the spectrum of the SVC polarization degree. The peak increases and moves towards higher frequency with the magnetic field. The peak position is in the wavelength range of 2 - 9 cm.

(6) The spectrum of the geometry of the S-component source (i.e. local radio source) rises with increasing magnetic field. Moreover, the geometrical parameters monotonically increase with the wavelength. That is to say, the height and the radius of the source increase with increasing magnetic field and/or wavelength.

This research on the SVC radiation variation with the magnetic field of active regions has an important theoretical significance and a useful reference value in radio astrophysics and solar physics.

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