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Computation and analysis of gyrosyncrothron emission in solar flares

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Abstract. The emission spectrum of solar flares in the range of microwave wavelengths is known to be due to the gyrosynchrotron mechanism. In this work, this emission for a few solar flares of the cycle 23 observed by the Nobeyama Radio Observatory instruments were analyzed. The information provided by the time profiles and the event images were used as the input parameters in the numerical computation of two flares' spectrum. A priori information obtained from the data was the electron spectral index, the emitting area and the angle between the magnetic field lines and the observer's line of sight. With these in hands, and following Dulk (1985) and Costa (2005) the first guesses of the magnetic field intensities were obtained. Based on a homogeneous source model where the depth is considered to be a fraction of the observed width, the emission spectra were fitted with the χ^2 criterion, with the non-thermal electron number density and the magnetic induction set as free parameters. With this simplified scenario the values obtained for one of the events were the typical, as can be seen from other flares' analysis in the literature. This flare showed an emission peak at 17 GHz resulting in an inferred magnetic induction of 663 G and an electron density of $2.6\text{x}10^6$ cm^{-3}. For the second flare, the fitted spectrum showed many harmonics in frequencies higher than the peak emission (9 GHz) that resulted in a very high magnetic induction (2183 G) and a very low electron density ($3.8\text{x}10^5$ cm^{-3}). This analysis was a first step to model a sample of selected flares using anisotropic magnetic fields extrapolated from the photosphere using the force-free hypothesis. The final analysis will be done solving the transfer equation in this anisotropic ambient.

Key words. Sun: solar flares – Sun: microwaves – Sun: magnetic field

1. Introduction

The radiative transfer equation for the gyrosynchrotron emission mechanism has numerical solutions determined by Ramaty (1969). These are the base for a computational method developed by Simões (2005). This code calculates the emission of a 3D homogeneous region with isotropic magnetic field distribution. However, anisotropic pitch-angle distributions and multi power law electron energy distribution are incorporated. This code is used to fit flare's power spectrum derived from observations by Nobeyama Radio Observatory. The spectral index of photons was obtained fitting the spectra with the power law proposed by Stähli (1989). The electron spectral index (δ) was calculated using a known relation by Dulk (1985) which relates the peak frequency and

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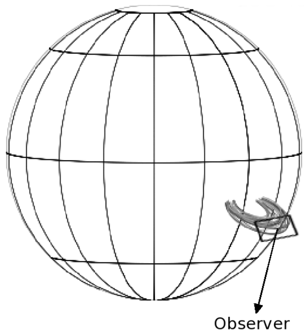

Fig. 1. Considered geometry for the magnetic loop: θ is the angle between the tangential plane to the loop top and the observer's line of sight.

Table 1. Starting parameters for the fitting of gyrosynchrotron power spectrum.

Event	2000-03-13	2003-05-27
δ	3.9	3.0
θ (°)	86.9	98.6
Ω (arcsec)	50	30
L (cm)	1.19x10^9	7.12x10^8
N (cm^{-3})	1.0x10^7	1.0x10^7
B_D (G)	1267	365
B_C (G)	1791	555

magnetic parameters. The magnetic induction B was calculated with expressions of Dulk (1985) (B_D) and Costa (2005) (B_C) which are valid under slightly different conditions. The magnetic structure is a loop and the optically thin emission is considered to come from the top of this loop. Thus the angle (θ) between the magnetic field direction and the observer's line of sight is determined with respect to the plane of the loop top region, as illustrated in Fig. 1.

The emitting region has diameter Ω determined from radio images by the Nobeyama Radioheliograph, and depth L which is a fraction of the first. The proton number density was set as 1.0x10^9 cm^{-3} and the energy range of the electrons was between 10 KeV and 100 MeV. The electron number density (N) and the magnetic induction were set as parameters to be adjusted. The best fit spectrum was determined by the minimum χ^2 between the observed and calculated fluxes. The frequencies of the optically thin regime have a greater weight in this criterion. The fluxes were calibrated by the pre-event mean value in each of the observed frequencies (1, 2, 3.75, 9.4, 17, 35 and 80 GHz).

2. Results

The results for two flares, occurred at 2000-03-13, 05:03 UT and 2003-05-27, 23:02 UT, are shown in the following figures. Fig. 2 presents the spectra fitted with the power law of Stähli (1989), from where the spectral index of photons were obtained: 2.3 and 1.5 in the optically thin regime of the first and second flares, respectively. The triangles are the observed fluxes, the asterisks are the minimized χ^2 results and the curve is the above mentioned power law. Fig. 3 presents the results of the gyrosynchrotron emission for a homogeneous solution of the radiative transfer best fit. Again, the triangles are the observed fluxes, the asterisks are the minimized χ^2 result and the curve is the gyrosynchrotron emission calculated in the range of 1 to 80 GHz. Table 1 shows the values adopted as starting parameters in these calculations. The first flare had its best fit for a higher magnetic induction with the presence of harmonics structures near the peak. This effect remained with anisotropic pitch-angle distributions, as this consideration is important only when the brightness distribution is observed. The second flare presents a typical spectrum where the peak frequency is right moved and the peak flux is smaller with respect to observations. This indicates that magnetic parameters and the source size were underestimated.

3. Conclusions

The harmonics in the optically thin regime of the first flare are due the isotropic magnetic distribution adopted. This conclusion comes from the high dependence of the gyrosynchrotron emission with magnetic induction parameters. In a subsequent step of this work an anisotropic magnetic field will be incorporated to the radiative transfer; this should im-

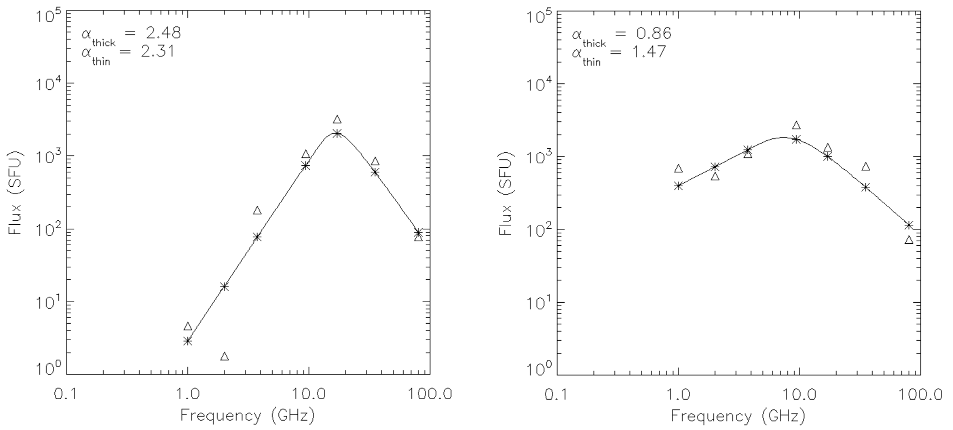

Fig. 2. Fitted power law spectra for the 2000-03-13 at 05:03 UT (left) and 2003-05-27 at 23:02 UT (right) flares.

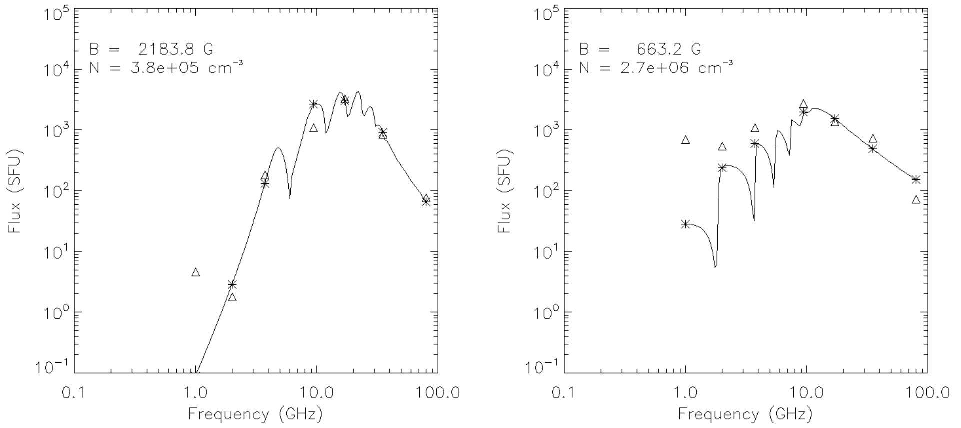

Fig. 3. Gyrosynchrotron emission spectrum for the 2000-03-13 event (left) and the 2003-05-27 event (right). The best results for the magnetic field intensity B and the electron number density N are shown in each case.

prove the results for the gyrosynchrotron emission. Another possible refinement is to consider anisotropic electron distributions along the magnetic loop. The underestimated fluxes derived in the optically thick regime of the second flare are possibly due the consideration of loop top emission. This event should be analyzed in other energy ranges to correctly identify the emitting sources of this regime.

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