Observations and Models of a Flaring Loop

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Abstract. Simultaneous images of a flaring loop at two frequencies are used to model the magnetic structure of the loop and the energy distribution of the radiating electrons. The imaging data were obtained with the VLA at 5 and 15 GHz. Additional spectral data were provided by the OVRO Solar Array at several frequencies between 2 GHz and 18 GHz. At 15 GHz, the flare emission was optically thin and came from the footpoints of the flaring loop, while at 5 GHz the loop itself was outlined. Most of the 5 GHz emission was optically thick and its spatial maximum was close to the loop top. The 5 GHz emission does not reach down to the 15 GHz footpoints. We compare the observations with calculations of gyrosynchrotron emission from an inhomogeneous magnetic loop in order to determine the conditions in the flaring loop. The best fit to the OVRO fluxes was reached with a model flaring loop with photospheric footpoint magnetic field strength of 870 G. The energy spectral index of the energetic electrons was 3.7 and their number density was \(7.9 \times 10^7\) cm\(^{-3}\). The low and high energy cutoffs of the nonthermal electrons were 8 and 210 keV. The 5 GHz emission in this model is at low harmonics (3–7) and harmonic effects are responsible for the weak 5 GHz emission at the footpoints. That model reproduced well the high frequency part of the OVRO flux spectrum as well as the VLA spatial structure.

1. Introduction

The basic emission mechanism of solar microwave bursts is gyrosynchrotron from mildly relativistic electrons trapped in flaring loops. The general tendency is that observations at high frequencies show compact sources, presumably associated with the footpoints of flaring loops, while at low frequencies there is a tendency for more extended sources, indicating emission from the entire loop.

We present VLA and OVRO observations of a simple small flare. We try to reproduce the observed microwave morphology of the VLA maps as well as the OVRO flux spectrum using an inhomogeneous model of gyrosynchrotron emission. Comparison between the observations and models will allow us to derive constraints about the magnetic configuration of the flaring region and the physical properties of the nonthermal electrons.

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Figure 1. Contour plots of the VLA flare at the time of maximum overlaid on a KPNO magnetogram. The total intensity $I$ snapshot maps are on the left and the circular polarization $V$ maps on the right. The solid contours show the 5 GHz emission and the dashed contours show the 15 GHz emission. In the 5 GHz $V$ map the thick contours represent positive brightness temperatures. The white contours in both images show the sunspot-associated emission at 15 GHz. The contour levels in the $I$ maps are $(2.25, 3, 3.75, 4.5, 6, 7.5, 9, 12, 15, 24) \times 10^5$ K and $(0.2, 0.4, 0.9, 1.4, 1.9, 2.3) \times 10^6$ K for 5 GHz and 15 GHz respectively. The contour levels in the $V$ maps are $(-0.55, -0.45, -0.40, -0.25, -0.20, -0.15, -0.07, 0.07) \times 10^5$ K and $(-23, -18, -14, -9, -4.5, -3.3, -1.6, -1.2) \times 10^5$ K for 5 GHz and 15 GHz respectively.

2. Data Analysis

The observations were carried out on July 1, 1992. The VLA observed the flare at 5 GHz and 15 GHz (see fig. 1). The heliographic coordinates of the center of the field of view at both frequencies were N15E53. The flare occurred from 17:17 UT to 17:40 UT.

The spectral data consisted of total power fluxes obtained with the two 27-m OVRO antennas (antennas 1 and 2) at several frequencies between 2 GHz and 18 GHz (see fig. 2).

3. Model Computations and Results

We adopt a model of semicircular field lines above a line dipole, in which magnetic field varies inversely with the square of the distance from the line dipole. We compute gyrosynchrotron emission from the loop using a code in which the gyrosynchrotron emissivity and opacity are calculated exactly at specified points along the loop, and the emitted radio flux is calculated using simple radiative transfer (see Nindos et al. 2000 for details on the computations and presentation of the full results).

The footpoint separation of the model loop is determined from the 15 GHz VLA images: it is $2.6 \times 10^9$ cm. The radio spectral index from the OVRO data gives a power–law energy spectral index of 3.7. The free parameters are the number density of the nonthermal electrons, their lower and upper cutoff energies, the heights above the solar surface of the lines of force of the magnetic field which form the loop and the strength of the magnetic field at the photo-
Figure 2. OVRO total power spectra from antennas 1 and 2, at the time of maximum. The dotted curve is the best fit model to the OVRO spectra.

sphere. The orientation of the loop is also variable subject to the constraint that it should resemble the observed loop.

The best fit to the OVRO fluxes at the peak of the event (see fig. 2) was obtained with a model loop located at heliographic longitude 50° east and latitude 50° north and with a 45° orientation with respect to the local north. The photospheric field strength at the footpoints of the model loop was 870 G. The heights above the solar surface of the upper and lower lines of force of the magnetic field which formed the loop were $1.9 \times 10^9$ cm and $1.8 \times 10^9$ cm. The transverse dimension of the loop was $5.25 \times 10^7$ cm. The loop was filled with energetic electrons with density $7.9 \times 10^7$ cm$^{-3}$ and low and high energy cutoffs at 8 keV and 210 keV, respectively.

4. Conclusions

The spatial structure of our best fit model (fig. 3) was in agreement with most of the features of the VLA flare. At 15 GHz, the model emission showed optically thin highly-polarized emission from the footpoints of the loop. At 5 GHz the model emission came from the entire loop and most of it was optically thick.

The model field strength was 870 G at the photosphere and 282 G at the loop top. Thus, it was strong enough so that the 5 GHz emission came from low harmonics of the gyrofrequency (harmonics 3–7). The harmonic structure is especially prominent in the $I$ model (see fig. 3). The high magnetic fields also explain the interesting feature that the 5 GHz emission did not extend all the way down to the feet of the loop. At the eastern edge of the loop we have gyrosynchrotron emission from harmonics 3–5 of the gyrofrequency. Local $I$
peaks are produced when the angle between the magnetic field and the line of sight is sufficient. The convolution of the model $I$ profile with the VLA beam washes out those local peaks and makes the bright 5 GHz emission appear not to overlap with the peak 15 GHz emission.

The fact that we placed our model loop at N50E50 while the real location of the flare was N20E50 indicates that the loop was tilted about 30° with respect to the local vertical. Both the thickness of the loop and its transverse dimension are small compared to the footpoint separation. Thicker loops can also give satisfactory morphologies at 5 and 15 GHz (provided that we change the other free parameters appropriately) but the resulting fluxes are not consistent with the OVRO values. The high density of energetic electrons in our model was necessary to make the 5 GHz emission optically thick because we used a thin loop and suggests that both the acceleration process and trapping of energetic electrons were efficient in this flaring loop. The absence of electrons above 210 keV is necessary to explain why no emission was observed from loop top at 15 GHz.

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References