The Post-Eruptive Arcade Formation in The Limb Event on July 31, 2004 From Microwave Solar Observations with the RATAN-600 Radio Telescope.

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Abstract A CME/flare event occurred at the western limb on 31 July 2004. Five successive multi-wavelength scans in centimeter range were obtained with the RATAN-600 radio telescope starting at the early stage of post-eruptive arcade formation (24 min after a C8.3 flare peak) and lasting for 4 hours. Microwave radio emission of the arcade was rather intense at initial stage indicating a predominant contribution of thermal emission and then considerably decreased during the decay phase. Its maximum was co-spatial with the 195 Å Fe XII loop tops. At the end of microwave observations the contribution of the emission from accelerated particles became significant. The similarity of microwave characteristics of two eruptive events (on 31 July 2004 at the western limb and on 25 January 2007 at the eastern limb) is shown.

Keywords: radio radiation, solar flares, post-eruptive arcades, coronal mass ejections (CMEs)

Introduction

Systems of post-eruptive arcades could be formed in events of a various importance. We suppose that one of the necessary conditions for that is a CME development followed by removal of the main part of the gas mass far into interplanetary space. However, a part of the matter could be held into coronal layers of active regions and take part in the arcade formation. Observations of post-eruptive arcades in various spectral regions were analyzed in several papers [1-3]. Unlike the previously studied events related to flares of the M or X GOES classes, we tried to observe with the RATAN-600 radio telescope the formation of a post-eruptive arcade in a weaker event (not exceeding the GOES class C). In this paper we discuss the observations of different cases of post-eruptive arcade formation in events with weak flares (GOES class C) just at the initial stage. In order to confirm our supposition, it is necessary to analyze the role of thermal and non-thermal processes in the source region of the subsequent arcade formation. One might expect the contribution of the accelerated particles to the microwave emission to be minimal in such events thus enabling one to study plasma parameters in post-eruptive arcades. We compare the microwave observations (RATAN-600) during the initial stage of the post-eruptive arcade formation in the limb event on 31 July 2004 with those observed in limb event on 25 January 2007 [4].

Observations and Methods

On 31 July 2004 solar observations at the radio telescope RATAN-600 were carried out in the meridian and four azimuths at different positional angles with time-intervals of about one hour. Right and left circularly polarized components were recorded at several wavelengths simultaneously within the wavelength range of 1.8 – 5.0 cm (6-15 GHz) during the Sun crossing the fixed diagram of antenna.

The solar observations were made at 07:21, 08:20, 09:20, 10:19 and 11:18 UT. The onset of the first C8.4 class flare was at 05:16 UT (the peak at 06:57 UT); next C5.3 class flare occurred in the same AR NOAA 10652 behind the western limb with the peak emission at 11:01 UT). So, the first RATAN-600 observation was made 24 min after C8.4 flare peak.

According to SOHO/EIT data (at 195 Å) the rising of the post-eruptive loops was observed until 20 UT. The RHESSI data showed the increasing of the low-energy X-ray flux (3-6, 6-12, 12-25 keV) during this event with maximum at the impulsive phase of the flare.

Results

Fig.1 shows the off-limb radio source extracted from the one-dimensional RATAN-600 solar scan (Stokes "I" – dark line, Stokes "V" – light line) at 3.2 cm overlaid on the SOHO/EIT 195 Å solar image. Vertical right scale is the exceeding emission of the radio source above the quit Sun level. The error of co-alignment of the solar scans and 195 Å images is assumed to be 5 arc sec. Here the position of X-ray emission in the channel 6-12 keV (RHESSI) is shown by dotted lines (contour levels are 90% and 60% of maximum). Microwave radio emission of the post-eruptive arcade was rather intensive at initial stage and considerably decreased at decay stage; its peak was positioned on the 195 Å loop tops.

In Fig.2 one can see the total flux spectra of the microwave source associated with the loop top of arcade obtained from 5 observations with the RATAN-600 on 31 July 2004 (right – the time of observations).

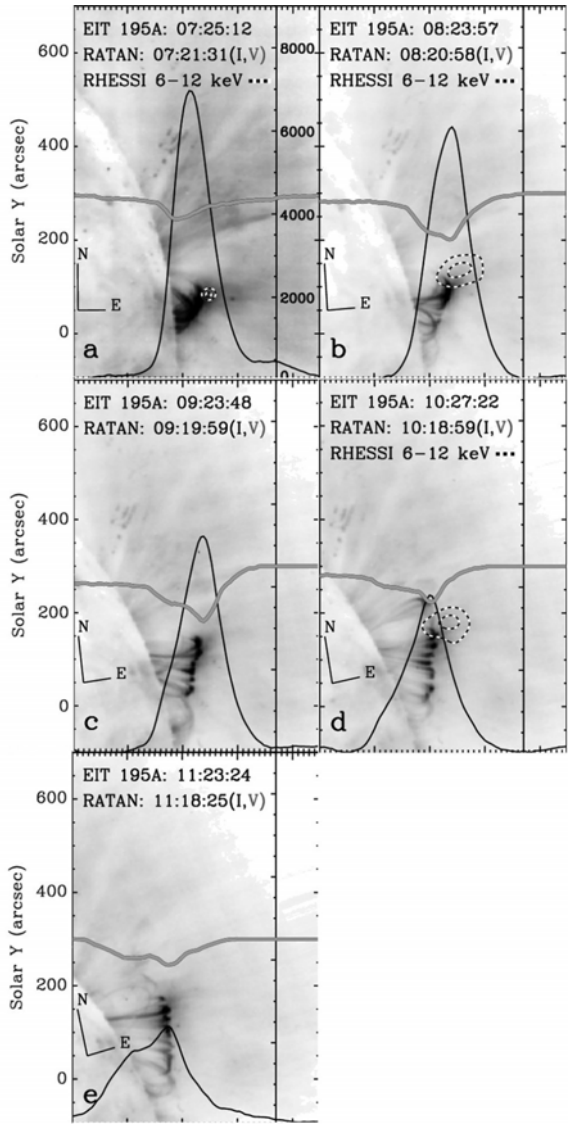

Fig.1. Identification of the microwave off- limb source.

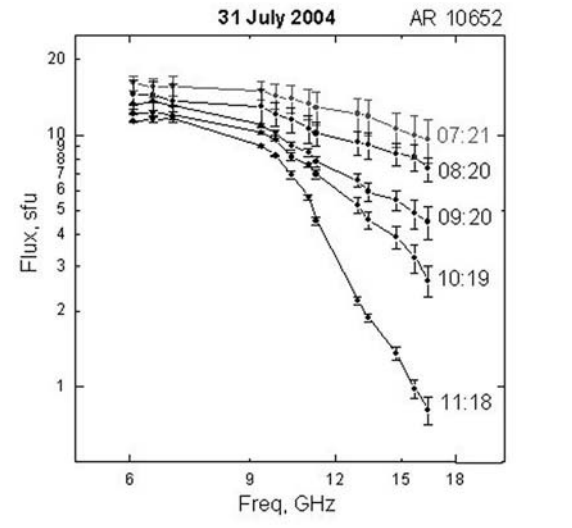

Fig.2. Total flux microwave spectra of the off-limb radio source conclude in not very power events the thermal associated with the post-eruptive arcade at 31 July 2004

The microwave spectra show the predominant thermal emission during one hour after the eruption. Later the intensity of radio emission and thermal contribution fast decreased. Assuming bremsstrahlung as a predominant mechanism of microwave emission and T(K)=1.5×10^6, we estimate from plasma parameters in the loop top: the emission measure to be EM=2.9×10^{48} cm^{-3} and plasma density 5.1×10^9 cm^{-3}.

The X-ray source was registered in 3-6, 6-12, 12-25 keV channels from 06 UT. Mean HXR photon spectra obtained with RHESSI data are shown in Fig.4 by dotes. The approximation by the thermal model is shown by solid line. One can see that the best fit was obtained for the optically thin bremsstrahlung radiation function (vth) for two first spectra with parameters of the thermal model: Te=12.5× 10^6 K, EM=1.4×10^{48} cm^{-3} (07:15 UT) and Te=11×10^6 K, EM=1.6×10^{48} cm^{-3}, (08:20 UT). This result confirms the thermal nature of the observed X-ray source at early stage of arcade formation. At the late phase (10:19 UT) the X-emission approximated the thermal model with a small contribution non-thermal emission with plasma parameters: Te=8.9×10^6 K, EM=1.0×10^{47} cm^{-3} (γ=6.2).

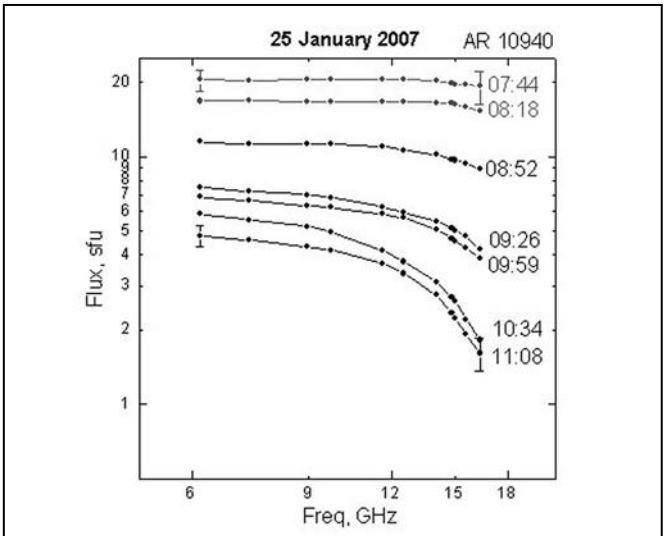

Fig.3. Total flux microwave spectra at 25 January 2007 as in (Fig.2).

Discussion

We may compare microwave characteristics of post-eruptive arcades in two active events – on 31 July 2004 (under consideration) at the western limb and on 25 January 2007 at the eastern limb which consisted of the flare C6.3 and CME [4]. Fig.3 shows the total spectra from the source of microwave emission associated of the arcade observed on 25 January 2007. Here the first observation with the RATAN-600 was 30 min after the peak of the flare C6.3. These spectra show the predominant thermal emission of plasma at the early stage of arcade formation.

Assuming bremsstrahlung as a predominant mechanism of microwave emission and T=5×10^6 K, we estimate the emission measure as EM=14.6×10^{48} cm^{-3}

(07:44 UT) and EM=7.5×10^{48} cm^{-3} (08:18 UT) on 25 January 2007 from microwave data.

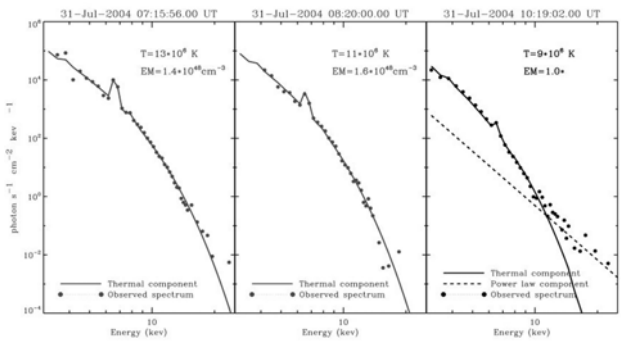

Fig.4. The X-ray photon spectra of the off-limb source on 31 July 2004 obtained by RHESSI.

The difference of the plasma parameters in post-eruptive arcades at the early stage of its formation in these two events are likely due to different scenarios of related flares: the common scenario – the loops keep back at high corona during long time; the dynamical scenario – the loops rise into corona and decay.

The predominant thermal emission at early stage of arcade formation has been also shown in the limb event on 2 December 2003 [5]. We may conclude the thermal emission of the large hot plasma cloud associated with the post-eruptive arcade dominates in microwave and X-ray emission of loop tops of arcades at the early stage of its formation in not very power events.

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