A Microwave Imaging Observation of an Electron Stream in a Solar Flare by Nobeyama Radioheliograph

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Abstract

We report a Nobeyama Radioheliograph microwave observation in a flare of a propagating feature of non-thermal emission to propagate from one end of the loop to the other with a speed of 9×10^4 km s^{-1}. We interpret this microwave is emitted from streaming electrons. From the comparison of energies of the electrons that should emit the microwave with their observed apparent speed, we suggest that the high energy electrons possibly have large (> 70 degree) pitch angles when they are injected.

1. Introduction

There is a few example of observation which succeeds in detecting the motion of the accelerated electrons as a series of images in solar flares. Motion at 3000 km s^{-1} was reported by Bastian et al.[1] using VLA observations at 8.4 and 15 GHz with a time resolution of 0.2 s. White, Janardhan, & Kundu [5] found the propagation of a non-thermal disturbance at a speed of 26,000 km s^{-1} at 0.33 GHz. In this short report, we introduce our observation of an additional example in which the apparent motion of the non-thermal emitting source has an apparent velocity of 30 % of the light speed [6].

2. Observations

This flare occurred on August 28, 1999. The GOES soft X-ray class was M2.8. It is observed by the Nobeyama Radioheliograph in microwave frequencies. The temporal resolution is 0.1 s and the spatial resolution is approximately 15 and 7 arcsec at 17 and 34 GHz, respectively. The main microwave structure of the flare consists of a point source and an elongated one (left panel of Fig 1). From the spatial coalignment with the magnetograms obtained by SOHO/MDI,

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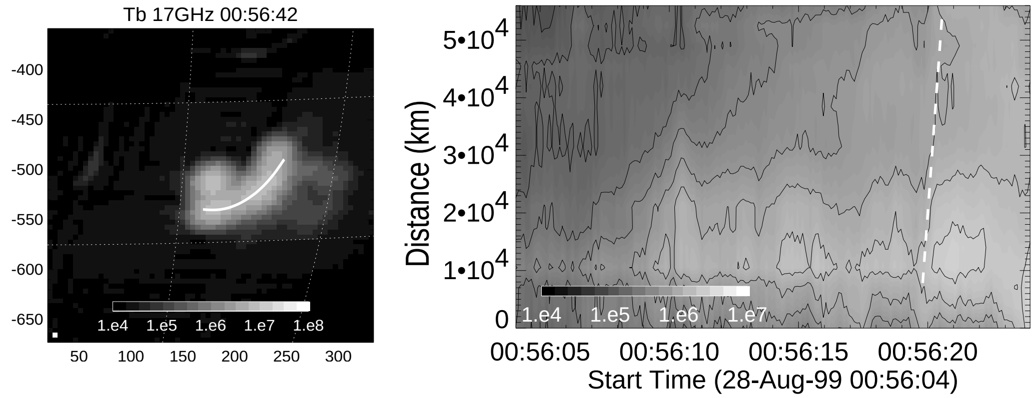

Fig. 1. (Left) Intensity (brightness temperature) map in 17 GHz. The solar north is up, and the solar east is left. The unit of scale is arcsec (i.e., about 700 km on the solar surface). (Right) Time variation of the 17 GHz intensity (brightness temperature) distribution along the microwave 'loop' indicated by the thick solid white line in the left panel. The levels of the gray-scale plot are shown by the color bar in unit of Kelvin. The left lower corner of the loop corresponds to the position '0 km' in the vertical axis of the right panel. Note the propagation around 00:56:20 UT whose speed is $\approx 9 \times 10^4$ km s^{-1} (indicated by thick white dashed line).

it is shown that the point source is located near a sunspot. And also it is shown that the elongated source is a magnetic loop. We can interpret the emission from the elongated source to be due to the non-thermal gyrosynchrotron mechanism based on the diagnostics of the microwave intensity and its spectrum.

We find several propagation features from the south-east end to the north-west end of the elongated loop. Right panel of Fig 1 shows the temporal evolution of the one-dimensional strip which is extracted along the loop source. The most significant is the propagation event starting at 00:56:19.66. Propagating profiles from the bottom of the plot (corresponding to the south-east end) to the top (the north-west end) can be seen. The propagation duration is 0.5 second from 00:56:19.66 to 00:56:20.16 UT and the distance is 4.5×10^4 km. Thus, the speed is estimated to be 9.0 $\times 10^4$ km s^{-1} that is 30 % of the light speed.

3. Discussion

We interpret this propagating source is emitted from streaming electrons. The energy of electrons which may mostly contribute to the 17 GHz emission in this event can be estimated as 1.3 MeV based on the observation of magnetic field strength and the microwave spectrum [2]. Thus, the velocity of the electrons is close to the light speed. On the other hand, an apparent velocity is only 9×10^4 km s^{-1}. If we suppose that the bulk of energetic electrons was injected into the magnetic loop at some large angle to the field lines, then one can explain

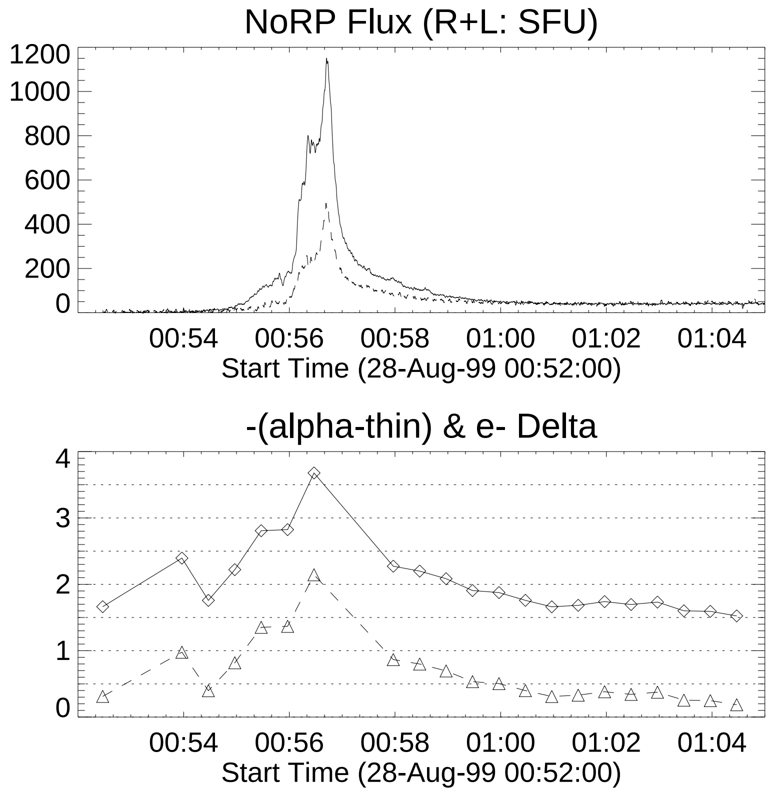

Fig. 2. (Top) Microwave fluxes F_ν in 9 GHz (solid) and 17 GHz (dashed) as a function of time observed by Nobeyama Radio Polarimeters. (Bottom) The dashed line indicates the index $|\alpha|$ of microwave flux (where $F_\nu \propto \nu^\alpha$, ν is the frequency,) obtained by fitting the optically-thin side (in the higher frequencies) of the spectrum by a power-law function. The solid line indicates the index δ of the electron distribution function derived from α based on Dulk's formula [3].

the low apparent velocity by the fact that the electrons were rotating around the magnetic field lines and the effective path was much longer than the apparent length of the loops. In this case, the pitch angle of the electrons is $\theta_{\rm pitch} \approx \arccos(v/c) \approx 70$ degree where v is the apparent velocity $v \approx 9 \times 10^4$ km s^{-1} and c is the speed of light. This may suggest that there is a possibility that the high energy electrons have large (> 70 degree) pitch angles when they are injected.

Melnikov, Shibasaki, & Reznikova [4] analyzed several events including this one, and suggested that the high-energy electrons in a flare have pitch-angle anisotropy. They found the flare loops in microwave have highly inhomogeneous distributions, i.e., the loop tops are generally brighter than footpoints. It is considered that the accumulation of the accelerated electrons near the top can be due to the strong trapping effect of the large pitch angle electrons injected near the loop top.

Figure 2 shows the fluxes and the spectrum index in microwave obtained by Nobeyama Radio Polarimeters. The index α is derived by fitting the optically-thin side of the microwave spectrum with a power-law function, namely $F_\nu \propto \nu^\alpha$ where F_ν is microwave flux. The electron index δ is obtained based on Dulk's formula [3]. From these plots, two things can be found. First, the free streaming electrons have an index of $\delta \approx 4$ when they are injected. Second, the e-folding time of microwave flux is about 20 sec. If we assume that this e-folding decay is due to the Coulomb collision of the trapped electrons and that the electrons have energy of 1 MeV, the background density is 3×10^{11} cm^{-3}. From the magnetograph observation, the magnetic field strength is found to be 200 G in the middle area of the loop. The Alfvèn speed is, then, ≈ 1000 km s^{-1}. This is much smaller than the observed propagation speed and we can rule out the possibility of hydromagnetic process for the interpretation.

References

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