The Spatially Resolved Spectrum Analysis of Gradual Hardening Flare

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Abstract

We present examination of the multi-wavelength observation of a M8.2 flare which occurred on 2000 November 25. This flare gives us more detailed pictures of the gradual hard flare amd high energy particles than before the previous studies.We mainly discussed the magnetic trapping effect for them and the spatial distribution and the temporal variation of the indices of the electron energy spectrum inferred from hard X-ray(HXR) and microwave.The main results are as follows. (1) In this flare, the HXR emission is mainly produced by electrons which precipitate into choromosphere after magnetic mirroring in flare loops and their energy is under 1 MeV. (2) The microwave emission at flare loop top is produced by trapped electrons and their energy is over 1 MeV. (3) There are a break in the electron spectral index between lower energy electrons which have over 1 MeV and higher energy ones under 1 MeV, that is, it is possible that the initial acceleration mechanism of their electrons at flare are not same.

1. Introduction

In a gradual hard flare [4], the electron power-law spectrum become harder and harder at later phase of solar flare. Tsuneta [7] suggested that magnetic trapping of energetic electrons in a closed magnetic loop plays significant roles in the gradual hardening flare. We mainly discuss the spatial evolution and the temporal behavior of the electron energy spectrum inferred from HXR and microwave. It has been known that the HXR emission and the microwave emission in solar

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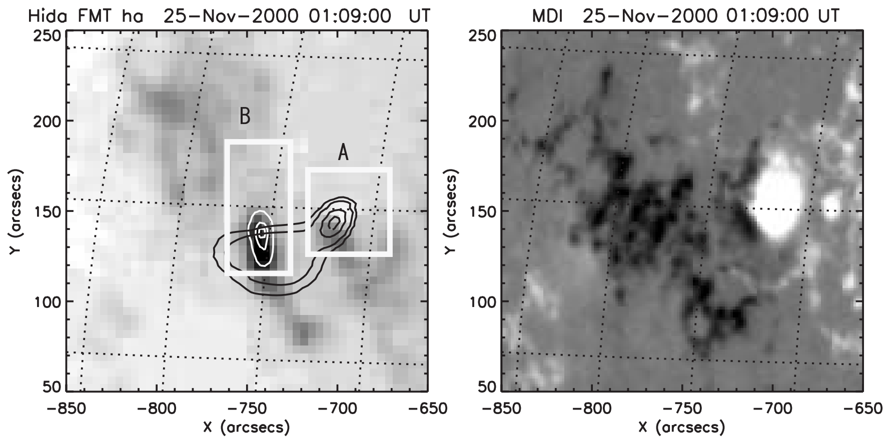

Fig. 1. Relation between asymmetry HXR and microwave sources location and magnetic field structure.

flare are well-correlated in time though the emission mechanisms of the HXR and microwave are quite different. Therefore, it is generally accepted that the HXR emissions and the microwave emissions produced by a common population. Assuming that the HXR emission is produced by lower energy counterpart of the same population, power-law distriution of the microwave emission which is produced by higher energy counterpart might be same as that of the HXR emission. However, in many previous studies [e.g. 2, 5], there are a breakup in the electron energy distribution.

A gradual hardening flare (M8.2 on the GOES scale) occurred in the region NOAA 9240 (N19, W78) on 2000 November 25. Fig.1 shows the HXR source and microwave source locations on the Hα image of the flare at 01:09:00 UT. The dominant HXR source which obtained from Yohkoh/HXT appeared as a single component located on an eastern footpoint of coronal loops. On the other hand, the dominant microwave sources appeared as a coronal loop structure. The eastern magnetic strength around eastern Hα footpoint and the western magnetic strength around the sunspot are approximately -70 Gauss and +800 Gauss, respectively. These figures imply that some accelerated particles precipitate along the magnetic line into the choromosphere at mainly eastern footpoint because the mirror effect is not effective at the weaker magnetic field and then HXR was emitted. Other accelerated particles are trapperd in the loops.

In this flare, the peak time of HXR and microwave emissions has the energy-dependence. The time of each impulsive peaks are the same at least or later at higher photon energies band or higher frequencies, respectively. These time delays are interpreted as the extra time needed to accelerate from low energies $\sim$ under 100 keV, which radiate the HXR, to higher energies $\sim$ over 300 keV, which radiate the microwave. Another interpretation is the magnetic trapping effect.

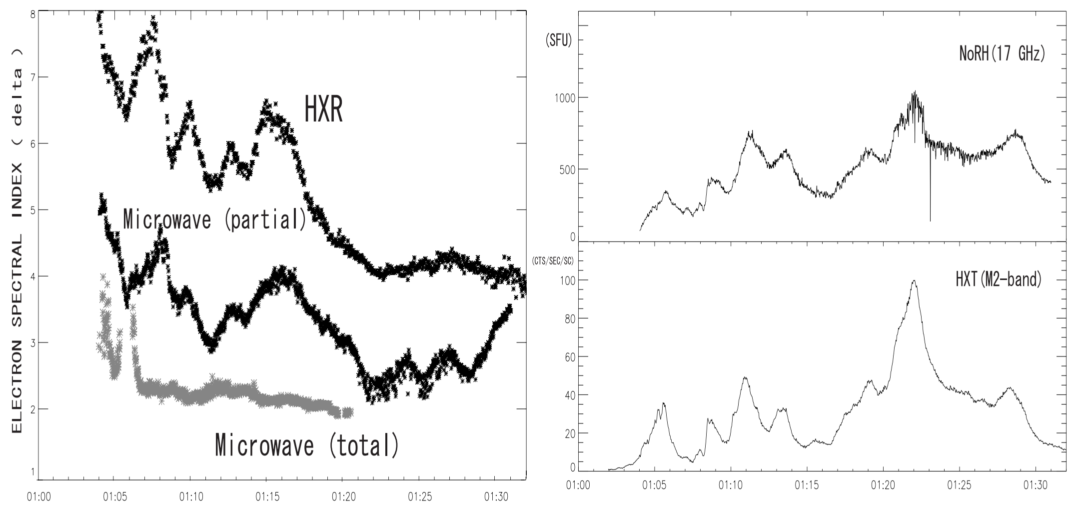

Fig. 2. *Left*; the time profiles of electron spectral indices obtained from *Yohkoh*/HXT (*top*) and NoRH from rectangle A (*middle*), NoRP (*bottom*). *Right*; the time profile of NoRH (17 GHz) total flux calculated from rectangle A(*top*), and that of Yohkoh/HXT M2-band (*bottom*).

The lower energy particles are more frequently scattered into the loss-cone and are lost from trapping by precipitation due to the energy dependence of Coulomb collisions.

2. Electron Energy Spectrum

The radio spectral index α is related to the spectrum index of the accelerated electrons δ, by $\delta = (1.22 - \alpha)/0.9$ [3]. In order to obtain α, we used the microwave data fitted from 1, 2, 3.75, 9.4, 17 and 35 GHz. On the other hand, there are two general models on radiation mechanism in HXR, the thin-target and the thick-target models. In the thick target model, the electron spectral index δ calculated from the photon spectral index γ as δ=γ+1.5 [6]. In order to obtain γ from the hard X-ray, we used the M2 (32.7-52.7 keV) and the H (52.7-92.8 keV) bands of *Yohkoh*/HXT.

In many previous studies of spectral analysis of solar flares, spectral index is culculated by physical parameter of whole sun (or whole active region). Here, we also measure the physical parameter in characteristic regions; western footpoint, eastern footpoint, refer to orders of A and B in Fig.1. and calculate the electron spectral index by using spatially resolved images. We defined the HXR total emission as total emission from eastern footpoint because the HXR source appeared at only, or at least dominantly, eastern footpont.

The temporal behavior of the microwave time profile of total emission estimated from only rectangle A amazingly looks like that of HXR. However, the electron spectral index of microwave is 2.0 - 2.5 harder than those of HXR. Furthermore, each peaks of the microwave time profile slightly delay about 15 seconds from those of HXR. This similarity and this obvious time delay and the spectral hardening suggest that the trapped particles which have same energy spectrum precipitate into choromosphere and emit HXR at eastern footpoint and microwave at sunspot. The energy of particles which produce the microwave may be rather small because the magnetic field strength around the sunspot is very strong. Because there are obvious time delay between the HXR emission and microwave emission, the energy of particles which produce the microwave is larger than that of particles which produce the HXR emission. However the difference of their spectrums is still remained as an unsolved problem.

While, in comparison with the HXR time profile, the peaks time of microwave delayed for about 30 seconds in the case of looptop source. Because the time delay there is larger than that of rectangle A, it is likely that magnetic trapping effect is more effective. That is, the energy of electrons which produce looptop microwave source is larger than that which produce western microwave footpoint source. The magnetic strength is not large at the looptop region. That is why the microwave emission at looptop is produced by very high energy particles. According to theoritivcal model (Bastian 1995), when the magnetic strength is about 100 Gauss and electron spectral index is 4, the electron energy which produce microwave emission is about 1.3 MeV.

We observed a guradual hard flare that occurred on 2000 Nov. 25. In this flare, the HXR emission is mainly produced by electrons which precipitate into choromosphere after magnetic mirroring and their energy is under 1 MeV. The microwave emission at looptop is produced by trapped electrons and their energy is over 1 MeV. We conclud that there are a break in the spectral index between electrons which have over 1 MeV and under 1 MeV.

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