Possible mechanisms of hard X-ray and microwave emission of occulted solar flares

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Abstract.
We present a preliminary analysis of the occulted flare SOL1999-Jun-04T07:00, using observations in X-rays and microwaves (MW). Hard X-ray (HXR) data were provided by the Konus-Wind experiment, and the soft X-ray (SXR) data from the GOES spacecraft. In the microwave (MW) range we used data from the Ondřejov radiospectrograph for MW dynamic spectra and data of Siberian Solar Radio Telescope for images at 5.7 GHz. The event consisted of an occulted flare and coronal HXR source. The MW time profile showed two peaks in MW range with the gyrosynchrotron spectral form. The maximum of the first peak was about 2 GHz, which indicates the low magnetic field strength in the emitting region. The second peak occurred about two minutes later and had a maximum of about 10 GHz that is more common for solar flares.

1. INTRODUCTION

The nature of particle acceleration during solar flares has remained uncertain for many decades. There are two trustworthy tracers of the accelerated electrons - hard X-ray (HXR) emission and microwave (MW) emission. We often assume that we observe HXR and MW emission by the same population of accelerated electrons. The sources of HXR emission are mainly located in the foot points of the flare loops. Presence of prominent coronal HXR sources during the flare thus implies some peculiarity in the event scenario and provides a possibility to test acceleration models.

Solar flares with footpoints fotuitously occulted by the solar limb allow us to reveal such coronal sources directly (e.g., Frost & Dennis 1971). There are several models which explain the origin of high coronal sources. They could be huge loops relating the occulted flare kernels with the above-the-limb loops, particles accelerated on shock waves from coronal mass ejections (CMEs) and caught by a magnetic trap, or just emission from the CME plasma itself. The presence of such sources shows that the morphology of coronal hard X-ray sources differs from that of the "ordinary" flares. The recent well-known such event SOL2014-09-01 was extremely geoeffective and showed a power-law spectral index remaining remarkably constant at a suggestive slope in the gradual HXR emission time profile. Similar events occur only rarely and the aim of our study is to find more events with this peculiarity and analyze its origin.

2. THE FIRST RESULTS OF SOL1999-06-04 EVENT ANALYSIS

We describe the flare SOL1999-08-04 that occurred on the western solar limb. The HXR flux measured by Konus-Wind (Aptekar et al 1995) shows three slowly-varying components (see Figure 1). The spectral photon index during the main peak looks stable as during SOL2014-09-01 event. Comparison of HXR data to MW emission obtained by the Nobeyama Radio Polarimeters (Nakajima et al., 1985) revealed that the onset of the main HXR peak coincided with the onset of the peak at 9.4 GHz flux. This development looks more like an ordinary flare. The maximum of MW flux at about 2 GHz preceded the HXR peak detected by Konus-Wind.

We compared the time profile at 2 GHz with the time profile of GOES 1-8 A flux time derivative. This indicates that an accelerated electron population indirectly involved in producing the thermal emission (Neupert effect). One can see that the peak at 2 GHz temporally coincided with the peak of the derivative. For more detailed analysis we used the dynamic spectra by the Ondřejov radiospectrograph in the

Czech Republic. This instrument records the solar radio spectrum at frequencies 0.80–5.00 GHz (Jiřička et al. 1993). We can see in the left panel of Figure 2 that the peak of the time derivative of the total flux temporally coincides with a burst drifting from the lower to higher frequencies. After this MW burst the peak of HXR flux by Konus-Wind then commenced. This could be an indicator of accelerated electron transport from the back-side of the Sun to the visible side. The images obtained by The Siberian Solar Radio Telescope (SSRT, Grechnev et al 2003) helped us to localize the position of this event (see Figure 2, right panel). It is above the western limb and coincides with the signature of the associated CME. We suggest that it was a fast CME with speed about 2230 km/s. Unfortunately, there was another M3.7 flare SOL1999-06-05T07:03 that occurred on the solar disk. The X-ray and MW emission of two flares could overlap which makes further quantitative analysis on this event more difficult. See additional details in http://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/A_remarkable,_but_confused,_coronal_hard_X-ray_source.

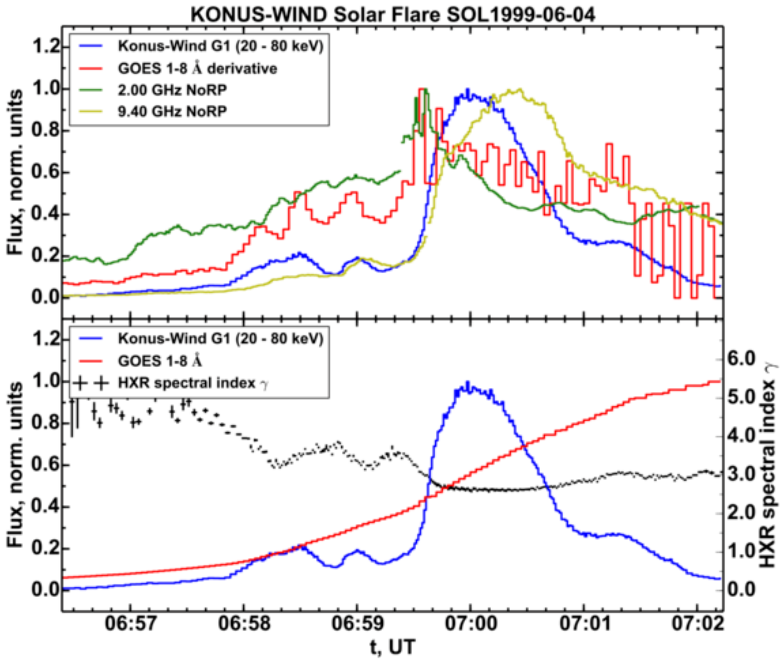

Figure 1. The time profiles of the of the SOL1999-Jun-04T07:00. The top panel shows Konus-Wind data (20-80 keV), derivative of GOES 1-8 A flux and microwave flux by Nobeyama radiopolarimeters (2 GHz and 9.4 GHz). The bottom panel shows Konus-Wind time profile, GOES 1-8 A flux and HXR photon spectral index.

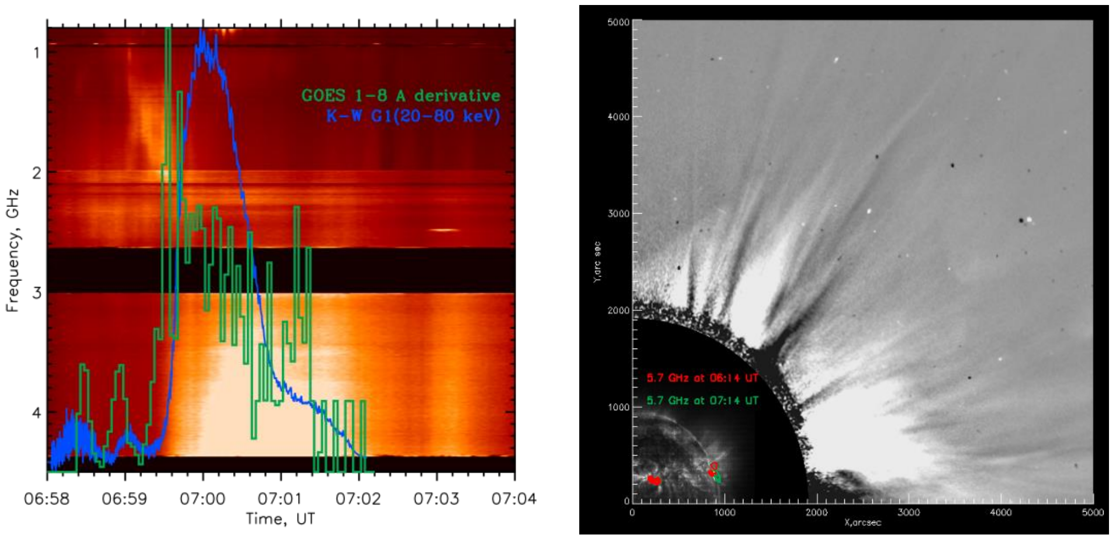

Figure 2. The left panel shows the dynamic spectrum by Ondřejov radiospectrograph overlaid by the time profiles of Konus-Wind data (20-80 keV) and derivative of GOES 1-8 A flux. The right panel presents the 195 Å image by SOHO/EIT and LASCO CME structure overlaid by SSRT microwave flare sources (green contours show the event and the red contours show the other active region).