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Hard X-Ray Emission of Solar Flares Measured by Lomonosov Space Mission

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Abstract. Solar hard X-ray and gamma-ray emission was measured by BDRG instrument, the part of set of instruments operated on board the Russian satellite Lomonosov from April 2016 until now (solar-synchronous orbit with altitude 490 km, inclination of 97.6 degrees). Lomonosov measurements (11 flares with the X-ray energy more than 10 keV, and more than half of them have class in soft X-rays less than C2) were compared to the data obtained by RHESSI and Fermi space observatories as well as the Nobeyama Radioheliograph operating at the same time. The quasi-periodicity with different periods were found in some of them.

Keywords. Sun: Flares, Sun: X-rays, gamma rays, Instrumentation: detectors

1. Introduction

Measurements of neutral emission of solar flares (X- and gamma-rays produced at the Sun), their time history and spectral shape, and comparing them with microwave emission of solar flare can provide us with the most direct important information about particle injection and acceleration processes in solar flares. Besides that, in the context of space weather, the data about the hardness of solar hard X-ray (HXR) and gamma-ray emission are important for estimating the possible damage that may be caused by a given flare to technical systems.

It is well known that the thermal flare emission of hot plasma produces soft X-rays (SXR). The most common classification of solar flares is based upon the energy of the thermal plasma defining its class in SXR according to observations on board GOES satellites (Garcia, 1994). The non-thermal emission of solar flares hard X-ray and gamma-emission is the result of charged particle interaction with the solar atmosphere. It is the superposition of electron bremsstrahlung continuum and gamma-ray line emission (see, e.g., Fletcher *et al.* 2011 and references therein).

2. Instrumentation

The Block of Detector of the Roentgen and Gamma emission (BDRG) instrument includes three identical detector units mounted on the spacecraft payload platform in such a way that their axes are shifted at 90 degrees from each other. Each detector has cosine angular dependence of sensitive area. The central axis, relatively to which the detector axes are inclined, is directed toward to the local Zenith. Thus, the total field of view of all three detectors is about 2 sr. Each BDRG detector unit is similar to the

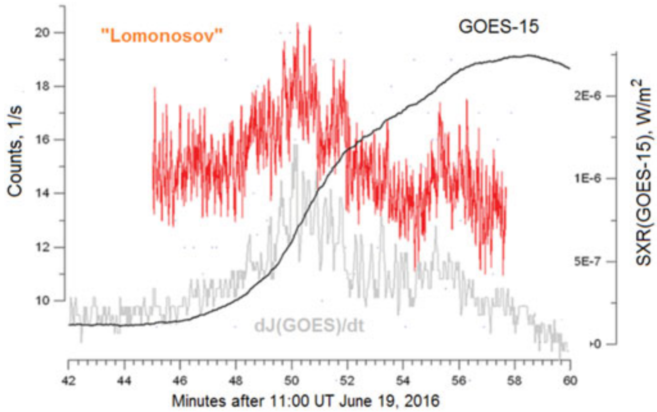

Figure 1. The time profiles of HXR emission measured during solar flare near noon UT June, 19, 2016 (C1.7) on board Lomonosov

Detector of the Roentgen and Gamma Emission (DRGE) detectors used for solar flare measurements on board Vernov satellite (Myagkova *et al.* 2016). It consists of optically coupled thin (0.3 cm) NaI(Tl) and considerably thick (1.7 cm) CsI(Tl) crystals. The diameter of both scintillators is 13 cm; NaI(Tl) is placed on top of the CsI(Tl) crystal, and both crystals are viewed by the same Photomultiplier tube Hammamatsu R877. Working ranges are 0.01-0.65 MeV for NaI(Tl) and 0.05-3 MeV for CsI(Tl). In this way, the NaI(Tl) works as the main detector for hard X-ray timing while the CsI(Tl) is used as an active shield against background gammas, and it can also detect gammas with energies up to a few MeV.

Information from BDRG contains a number of data frames formed continuously and a set of different data frames formed by trigger algorithms with characteristic times of 10 ms (fast), 1 s (slow) and 20 s (super-slow). Continuous data contain 3 main types of frames: monitoring (count rate in 8 energy channels for NaI(Tl) and CsI(Tl) from each BDRG detector, every 0.1 s), spectrum (724 channel spectra for NaI(Tl) and CsI(Tl) separately), and event mode (primary values of two scintillation components for a fixed number of events combined with time data). Trigger data contain the same set of different data frames, similar to the regular frames, with better time resolution (up to 0.001s).

3. Experimental data

The duty cycle for the detection of solar flares on board Lomonosov satellite was about 35-40 % as a result of its orbit parameters, so many flares were missed. However, 11 flares with HXR-emission were detected by Lomonosov during June-August 2016.

In Figure 1, HXR-emission produced in the June 19, 2016 solar flare of C1.7 GOES class (start at 11:44 UT, maximum at 11:58 UT), observed by Lomonosov is shown as an example. For comparison, the black line shows the change in SXR (GOES-15), and the gray line is the SXR flux derivative. It is clearly seen that the time profile of HXR and the derivative of SXR are strongly similar, in accordance with the Neupert effect (Neupert, 1968). Data on the solar HXR emission observed during the weak flares of C-class in soft X-rays can help solve the problem of so-called "cold" flares (e.g., Fleishman *et al.* 2011).

Lomonosov is a polar low-altitude satellite, thus during about a third of observational time the satellite crosses the Earth's radiation belts (ERB). Moreover, even in the rather suitable regions the observed increase of count rates may be caused by both solar flare radiation and electron precipitations. A possible way to specify the source of the

Table 1. The catalog of solar flares observed by Lomonosov satellite in June - August, 2016.

No	Day/month of 2006	Time, start-max-end SXR, hh:mm:ss (GOES)	Class SXR	Time, start-end HXR hh:mm (Lomonosov)	QPP	Other data	AR
1.	19/06	11:04-11:58-12:08	C1.7	11:44:20-11:57:40	+	GOES	12558
2.	09/07	09:01-09:05-09:05	B9.8	13:01:15-13:04:00	-	GOES	12564
3.	10/07	00:53-00:59-01:03	C8.6	00:56:20-00:59:40	+	F	12564
4.	18/07	08:09-08:23-08:32	C4.4	08:11:00-08:16:10	+	F	12567
5.	20/07	23:02-23:09-23:55	C5.0	23:04:45-23:05:30	-	F, N	12567
6.	21/07	00:42-00:46-00:50	M1.2	19:00:53-19:01:45	+	F, N	12567
7.	07/08	05:28-05:35-05:40	C1.3	05:33:55-05:34:10	+	F	12571
8.	07/08	10:18-10:24-10:29	C1.6	10:22:15-10:24:50	-	F	-
9.	11/08	08:34-08:38-08:42	B5.6	08:36:20-08:37:30	-	R	12574
10.	14/08	19:29-19:36-19:39	C1.1	19:34:00-19:35:15	-	R	12578
11.	15/08	00:17-00:23-00:29	C1.1	00:19:20-00:22:50	+	R	12578

detected signal is to compare time profiles observed on Lomonosov with the results of other experiments. We used the following data which is publicly available.

Characteristics of the flares detected on Lomonosov as well as SXR ones (GOES) are presented in Table 1: the day and the month, moments of the start, the maximum and the end of the SXR measured by GOES-15 satellite, flare class in SXR, the beginning and the end of the HXR emission with the energy more than 10 keV measured on board Lomonosov satellite, QPP - quasi-periodic pulsations (+ if they were detected), and the list of experiments in which, in addition to Lomonosov, the flare emission was detected: F - Fermi GBM ftp://legacy.gsfc.nasa.gov/glast/data/gbm/triggers/2016; N - Nobeyama http://solar.nro.nao.ac.jp/norh; R - RHESSI http://hesperia.gsfc.nasa.gov/rhessi3.

4. Summary

1. The time resolution of 0.1 seconds allows us to investigate in detail the fine temporal structure of HXR weak solar flares.

2. More than half of the HXR flares observed by Lomonosov had the SXR class lower than C2. It suggests that in these events solar electrons are accelerated without heating.

3. Experiment on board Lomonosov demonstrated that solar hard X-ray emission can be recorded during flares of the B-class in SXR.

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