OBSERVATIONS OF HARD X-RAY EMISSION OF SOLAR FLARES ON THE CUBSAT SATELLITES OF THE MOSCOW UNIVERSITY GROUP

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The possibilities of using cubesat nanosatellites to detect the hard X-ray radiation (HXR) from solar flares are shown. The results of HXR measurements of several flares in the energy range >30 keV using the DeCoR-1 and DeCoR-3 instruments installed on the *Avion* satellite are presented, as well as a table of flares observed in HXR on the MSU constellation cubesats from September 2023 to February 2024.

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INTRODUCTION

Solar flares are one of the most extreme manifestations of solar activity. During a flare, an enormous amount of energy is released in a short time across the entire radiation spectrum - from radio waves to X-ray and gamma radiation. Solar flares significantly affect space weather primarily through ionization of the upper layers of Earth's atmosphere on the sunlit side of Earth. They can also be accompanied by charged particle fluxes (protons, electrons accelerated directly in the flare and further accelerated in interplanetary space), resulting in deterioration of the radiation environment in near-Earth space (NES). Another phenomenon associated with flare processes on the Sun is coronal mass ejections (CMEs), which, when reaching Earth's orbit, become the cause of geomagnetic storms.

As is known, non-thermal radiation of solar flares, hard X-ray radiation (HXR) and gamma radiation, is the result of interaction between charged particles and the solar atmosphere (for example, [1] and references therein). The generally accepted classification of solar flares is based on the energy of thermal plasma, which is the source of soft X-ray radiation (SXR) of solar flares. The flare class is typically determined by the intensity of SXR radiation with wavelengths of 1–8 Å (corresponding to 1.5–12.5 keV) and 0.5–4 Å (corresponding to 3–25 keV), measured by the Earth's artificial satellite (EAS) of the *GOES* series. The temporal evolution of SXR, HXR, and γ-radiation of the Sun, as well as their energy spectrum in a wide energy range, provide us with information about particles accelerated directly in the flare on the Sun.

Modern experimental studies show that during solar flares, electrons are accelerated to high energies, leading to the heating of solar plasma. The standard model of a solar flare is described, for example, in the work [2]. In the pre-flare phase, the coronal plasma in the flare region slowly heats up, and magnetic energy builds up. Then, in the impulsive phase, as a result of magnetic reconnection at the loop apex, electron acceleration occurs. Accelerated electrons propagate along the magnetic loop to its footpoints, where, under thick-target conditions, they produce HXR through bremsstrahlung and heat the plasma to high temperatures observed in soft X-ray radiation. The hot plasma expands along the loop into the corona, a process called "evaporation." In the decay phase, the coronal plasma returns to its initial state.

This scenario can explain such experimental facts as the position of SXR and HXR sources, the excess of accelerated electron energy over the thermal energy contained in the soft X-ray source, and harder spectra at the loop footpoints compared to the upper sources.

The model described above is not the only one. For example, in paper [3], a collapsing magnetic trap model was proposed, for which an increase in temperature leads to a 6-8 order of magnitude increase in the number of quasi-thermal electrons capable of overcoming the "Coulomb loss barrier." In turn, this suggests the need for preheating of the background plasma to $\gtrsim 10$ MK, which may be accounted for by the betatron mechanism.

The physical properties of the particle acceleration region and the processes occurring in it require further study. An open question, in particular, remains about the reason for the presence or absence of the Neupert effect [4] in flares (correlation of soft X-ray flux with the cumulative hard X-ray flux) as a result of plasma heating by accelerated electrons.

Also, data on the detection of hard neutral radiation from solar flares with energies above 100 keV are of both scientific and practical interest, as hard X-ray radiation can be used as an alert for the appearance of solar cosmic ray (SCR) fluxes. The authors of the study [5] included among the necessary and sufficient observational conditions for real-time prediction of proton flares the generation of hard X-ray radiation with energy $E > 100$ keV with a duration of more than 5 min.

Furthermore, in the context of space weather tasks, it is of interest to register not only hard X-ray radiation from a solar flare on the same spacecraft, but also SCR fluxes formed after this flare. The results of measurements of SCR fluxes performed in experiments on SINP MSU cubesats are presented in publications [6, 7].

RESEARCH ON CUBESAT FORMAT SATELLITES

The purpose of this paper is to analyze the possibility of using not "classic" satellites, but nanosatellites of the CubeSat format for measuring hard X-ray radiation. This format was developed as a specific standard for small Earth artificial satellites with overall dimensions in the form of a cube with a side of 10 cm. The use of standards has made both the development of the devices themselves (by installing payloads on ready-made platforms) and their launch into near-Earth orbit, most often as a piggyback launch, significantly cheaper. Therefore, creating a nanosatellite has become a reality for many organizations, including research institutes and universities. Statistics on the use of CubeSats are reflected on the website https://www.nanosats.eu/. It should be noted that for modern tasks, satellites with dimensions of $10\times10\times10$ cm^3 (this size is designated as 1U) are often too small, and organizations use devices twice (2U), three times (3U), six times (6U) larger in size.

In addition to applied, commercial, educational projects, etc., an increasing number of CubeSats are being launched for scientific studies of various space phenomena, including those related to space weather and solar activity. For example, the article [8] presents the results of three generations of soft X-ray solar spectrometers MinXSS installed on CubeSats. In all three missions, the main scientific instrument is a silicon drift detector with a beryllium foil filter in the range of 0.5–20 keV. In the work [8], spectra are shown, and based on the intensity of the lines, temperature estimates were made during various solar events, which provided important information about processes on the Sun. The paper [9] presents the results of another experiment on observing the Sun in the soft X-ray range - on the CubeSat *SUNSTORM* 1 of the 2U format. From the comparison graphs of *SUNSTORM* 1 with the readings of *GOES* it follows that monitoring the Sun in soft X-ray radiation can be carried out using a constellation of CubeSats, provided that a continuous observation mode is ensured.

At Lomonosov Moscow State University Lomonosov University is developing the "Universat-SOCRAT" program [10], aimed at using small satellites for monitoring space threats, including radiation in near-Earth space and electromagnetic transients. As part of this program, since 2019 several successful cubesat launches have been carried out, with results including the observation of solar cosmic rays and space weather phenomena [6, 7, 10]. The observation of X-ray and gamma radiation from solar flares was not part of the tasks of these experiments, but it was fundamentally possible due to the presence of scintillation detectors with sufficient effective area.

Currently, cubesat mission projects are emerging that are directly aimed at observing solar flares in hard X-ray radiation. For example, the publication [11] describes the Italian Space Agency's CUSP project, which involves creating a constellation of two cubesats to measure the linear polarization of solar flares in the energy range of 20-100 keV using Compton scattering polarimeters. The paper [12] discusses the first results of two Czech cubesats - *GRBAlpha* (1U) and *VZLUSAT* 2 (3U), whose scientific objectives are primarily aimed at observing cosmic gamma-ray bursts. For this purpose, *GRBAlpha* (launched in March 2021) was equipped with a CsI(Tl)-based detector measuring 75×75×5 mm, operating in the range of ~30-900 keV. The *VZLUSAT* 2 cubesat, launched in January 2022 , carried a similar detector twice the size. Among the first results of *VZLUSAT* 2, besides several gamma-ray bursts, are two solar flares that occurred on 21.IV.2022 and 20.V.2022, with their time profiles presented at a time resolution of 1 s. In the paper [13], the *GRBAlpha* experiment is described in more detail, reporting 9 observed solar flares. On the website https://monoceros.physics.muni.cz/hea/GRBAlpha/ (viewed on 3.III.2024), there is an updated catalog of events observed by this cubesat, which as of early March 2024 includes at least 36 solar flares. For each of them, time profiles (light curves) are available in four energy channels, starting from ~70 keV.

Thus, the use of CubeSats, with proper experiment organization, allows obtaining quality data on fluxes and spectra of hard X-ray radiation from solar flares. Next, we will discuss the possibilities of observing hard X-ray radiation from solar flares in simpler and non-specialized experiments, using the example of the M.V. Lomonosov Moscow State University CubeSat constellation, operating from mid-2023 to the present.

EXPERIMENT

In this work, we used data on hard X-ray radiation fluxes obtained from several CubeSats launched on June 27, 2023 into a sun-synchronous orbit with an altitude of ~550 km and an inclination of 98°. These satellites are *Avion* , *Monitor* -2, -3, -4 and *UTMN* 2, which carry as payload the DeCoR, DeCoR-2, and DeCoR-3 scintillation detectors for registering hard X-ray and gamma radiation and charged particles, specially developed at SINP MSU for such experiments.

Satellites *Avion* and *Monitor* -2, along with traditional VHF radio transmitters, are equipped with S-band transmitters, allowing for practically continuous measurements.

A detailed description of the DeCoR-1, DeCoR-2, and DeCoR-3 instruments is provided in the article [14]. Hard X-ray radiation is registered using a CsI(Tl) scintillation crystal, whose geometric area and thickness for each instrument are specified in Table 1. In front of the CsI(Tl) crystal, there is a thin layer of plastic scintillator that serves both as a detector for charged particles (mainly electrons) and as an active shield for the CsI(Tl) channel, using the separation of events in different scintillators by the shape of the light pulse at the photodetector output.

The main parameters of the experiments are given in Table 1.

Table 1. Parameters of the Moscow University constellation CubeSats launched on June 27, 2023, as well as the detectors installed on them.

Project Name	Format	Frequency Range of Communication	Possible Volume of Transmitted Information	Installed Instruments	HXR Energy Range (as of 1.III.2024)	Area and Thickness of CsI(Tl)
AVION	6U	VHF, S	~ 50 MB/day	DeCoR-1 DeCoR-2 DeCoR-3	>40 keV >80 keV >30 keV	$18cm^2 \times$ 1cm $64cm^2 \times$ 1cm $9cm^2 \times$ 3cm
Monitor -2	3U	VHF, S	~ 50 MB/day	DeCoR-2 DeCoR-3	>80 keV >100 keV	$64cm^2 \times$ 1cm $36cm^2 \times$ 4cm
Monitor -3	3U	VHF	~ 0.3 MB/day	DeCoR-2	>80 keV	$64cm^2 \times$ 1cm
Monitor -4	3U	VHF	~ 0.3 MB/day	DeCoR-2	>80 keV	$64cm^2 \times$ 1cm
UTMN -2	3U	VHF	~ 0.3 MB/day	DeCoR-2	>80 keV	$64cm^2 \times$ 1cm

The main type of transmitted data in the considered experiments is monitoring with a time resolution of 1 s., and it is possible to change this value several times during the flight, both increasing and decreasing it. The lower threshold for photon detection is several tens of keV, which can also be changed during the flight, taking into account the background conditions in near-Earth orbit, and the detectors can be configured differently. The threshold values for each detector as of 1.III.2024 are indicated in Table 1.

Note that until this moment, at the flight test stage, only integral channels could be used (the sum of all events above a certain threshold energy). In the high-energy region, the channels are not limited by electronics saturation, as the instruments are configured so that a particle causing saturation will be registered. According to calibrations, electronics saturation occurred at energies of 1.5 MeV for DeCoR-1 of the *Avion* satellite and 3.5 MeV for DeCoR-3. Particles with higher energies do not make a significant contribution to count rates due to their low fluxes.

Also note that the sufficiently high thresholds >80 keV for all installed DeCoR-2 instruments are due to the fact that during flight tests in this period, their silicon photomultipliers (silicon photomultipliers, SiPM) were supplied with a reduced voltage level compared to ground calibrations, in which the threshold values were ~30 keV.

Currently, the flight testing phase has effectively ended, and in the future, not only integral monitoring channels will be transmitted to Earth from the *Avion* satellite. For example, for the

DeCoR-3 instrument, these will be channels corresponding to energy depositions >30, 100–300 and 300–3000 keV.

The experiments also implement an "event-by-event" recording mode, in which the registration time of each interaction is transmitted to Earth with microsecond accuracy, as well as scintillation parameters that allow determining the energy and type of event (quantum or particle).

Data from the MSU grouping cubesats are available as graphs and monitoring data tables on the SINP MSU space weather website at https://swx.sinp.msu.ru/tools/davisat.php.

MEASUREMENT RESULTS

The list of solar flares during which hard X-ray radiation was registered in experiments on the *Avion* and *Monitor* -4 cubesats in the period from September 2023 to February 2024 is given in Table 2.

Table 2. List of solar flares observed in hard X-ray radiation on cubesats of the MSU grouping.

No.	Date	SXR Time *GOES*	Class	Cubesat	HXR Time	Duration
1	19.IX.2023	20:01 – 20:14 – 20:21	M4.0	*Avion*	20:09 – 20:10	> 1 min (only the end is visible)
2	1.X.2023	03:21 – 03:24 – 03:30	C9.3	*Avion*	03:23 – 03:23	10 sec.
3	2.XI.2023	12:18 – 12:22 – 12:26	M1.6	*Avion*	12:22 – 12:22	< 20 s
4	15.XII.2023	07:03 – 07:15 – 07:23	M6.3	*Monitor* -4	07:09 – 07:16	7 min
5	4.I.2024	01:10 – 01:16 – 01:22	M1.1	*Avion*	01:12 – 01:14	2 min
6	29.I.2024	03:54 – 04:38 – 05:15	M6.8	*Avion*	04:16 – 04:21	5 min
7	8.II.2024	18:56 – 19:02 – 19:06	M1.3	*Avion*	19:01 – 19:02	25 s
8	9.II.2024	12:53 – 13:14 – 13:32	X3.3	*Avion*	13:04 – 13:07	3 min
9	22.II.2024	22:08 – 22:34 – 22:43	X6.3	*Avion*	22:25 – 22:42	17 min

In Fig. 1 (middle panel), the time dependence of count rates of the DeCoR-3 instrument installed on the *Avion* satellite during the M6.8 class flare on 29.I.2024 is shown. Not only the moment of HXR registration (marked with a yellow rectangle in Fig. 1) is shown, but a wider time interval (40 min), including the beginning and maximum intensity of SXR according to *GOES* data. The upper panel of Fig. 1 shows *GOES* data in the 0.1–0.8 and 0.05–0.4 nm channels, as well as, to estimate the derivative in these channels, the differences between the current value and the previous one measured a minute earlier are plotted.

During the time from 04:00 to 04:40, *Avion* completed almost half an orbit around the Earth, consequently crossing the outer radiation belt of the planet twice. Therefore, most of the increases in DeCoR-3 count rates are not related to flare radiation, but to bremsstrahlung of electrons from the Earth's outer radiation belt (ERB). Nevertheless, the flare was successfully registered on the

Avion cubesat, as during the HXR observation, the satellite was in the polar cap region, as evidenced by the values of the McIlwain parameter *L* [15], whose graph is presented in the lower panel of Fig. 1. *L* is a parameter used in magnetosphere physics, describing a specific set of planetary magnetic field lines. For example, $L = 2$ describes a set of Earth's magnetic field lines that cross Earth's magnetic equator at a distance of two Earth radii from the center of Earth. It can be said that *L* is somewhat analogous to magnetic latitude, but unlike latitude, it is positive for both northern and southern hemispheres.

To confirm that the enhancement observed in such complex background conditions is actually related to flare HXR, data obtained in the experiment on the cubesat *Avion* was compared with the results of flare radiation observations registered in other experiments. The middle panel of Fig. 1 shows, in addition to *Avion* data, also data from *Konus-WIND* [16] from the website https://ioffe.ru/LEA/Solar/index.ru.html (viewed on 1.III.2024), with the 18–76 keV channel selected. Data from the experiment with the STIX instrument [17] on *Solar Orbiter* was also used, available at https://datacenter.stix.i4ds.net/view/ql/lightcurves (viewed on 1.III.2024). Two channels closest to the energy range of DeKoR-3 were plotted, namely: 25–50 and 50–84 keV. Note that both *Solar Orbiter* and *WIND* are "classical" sized satellites conducting measurements outside Earth's radiation belts. The *Solar Orbiter* satellite at the time of the flare on 29.I.2024 was at a distance of ~0.9 AU from the Sun (Fig. 1 accounts for a delay of ~40.3 s). The angle at which the STIX instrument viewed the Sun differed from near-Earth experiments by 25.4°.

Fig. 1. Time profile of soft (*GOES*) and hard X-ray radiation (*Avion* , *Konus-WIND* , STIX) during the flare on 29.I.2024 (beginning at 03:54 UT), as well as the McIlwain parameter *L* for the cubesat *Avion* during the flare.

The fact that the HXR time profile obtained on *Avion* , as seen from Fig. 1, coincides in time, and has a similar shape to the profiles measured by *Konus-WIND* and *Solar Orbiter* , confirms the fact of HXR observation from this flare, and also indirectly indicates that the energy threshold of the DeCoR-3 instrument corresponds to the calibration value of 30 keV.

To determine whether a particular increase in a complex background environment is related to a solar flare, one can also use the comparison of time profiles of solar flares in HXR with the derivative of SXR, determined from *GOES* data, assuming the presence of the Neupert effect [4]. However, this method only works in case of profile coincidence (i.e., when confirmed); differences in profiles can also be observed when the Neupert effect is not fulfilled in the flare. The time profiles shown in Fig. 1 demonstrate this situation for the flare of 29.I.2024, when the Neupert effect is not fulfilled.

Fig. 2 shows another characteristic example of a solar flare observed in HXR on the *Avion* satellite. Data from the DeCoR-1 instrument were used.

Fig. 2. Time profiles of soft (*GOES*) and hard X-ray emission (DeCoR-1 instrument on the *Avion* satellite, *Konus-WIND* , STIX) during the flare of 02.XI.2023 (starting at 12:18 UT)

This is an M1.6 class flare on 2.XI.2023, observed by *GOES* in soft X-ray emission from 12:18 to 12:26 with a maximum at 12:22. This flare was recorded during the satellite *Avion* passage through the equatorial region, which eliminated the problem of separating flare emission from bremsstrahlung of electrons from the outer radiation belt. The upper panel of Fig. 2 also shows *GOES* data on SXR registration, and the lower panel includes data from *Avion* along with data from the *Konus -WIND* and STIX (*Solar Orbiter*) experiments. As can be seen from Fig. 2, the presented HXR profiles measured in all three experiments match well with each other in channels close in energy, but the time resolution in the experiments on *Avion* and *Konus-WIND* was sufficient to separate two peaks at the maximum of the flare's HXR. Judging by the coincidence of the time profiles obtained on *Avion* and *Konus-WIND* , several smaller increases that occurred from the 10th to the 20th second after the flare onset are also significant.

It should be noted that many flares listed in Table 2 are very short-duration events, and a third of them, including the one on November 2, 2023, were observed in HXR for less than a minute. The shape of the HXR pulse from such flares is close to the shape of gamma-ray bursts of astrophysical origin, so such flares will, like gamma-ray bursts, trigger the burst mode in instruments designed to observe them, which is typically used for detailed recording of the light curve. This triggering made it possible to obtain the profile of the November 2, 2023 flare on *Konus-WIND* with a time resolution of 0.064 s. The data from the *Konus-WIND* experiment, shown in Fig.2 (https://gcn.gsfc.nasa.gov/notices_k/auto/konus_20231102.44522, viewed on April 23, 2024), are taken from the General Coordinates Network (GCN) website—a network resource of the astrophysical gamma-ray burst research community. Similar practice of using burst mode for short-duration solar flares can be implemented in CubeSat experiments as well. However, in longer flares with slow HXR rises, the trigger will either not activate or will be difficult to configure due to false triggering from bremsstrahlung of radiation belt particles. Additionally, when using only the trigger mode, long-duration flares will not be recorded completely. This once again emphasizes the importance of combining continuous monitoring measurements with a time resolution of at least 1 s and recording individual events in maximum detail, limited primarily by the ability to transmit data to Earth.

DISCUSSION

The results obtained on the *Avion* satellite demonstrated that the use of CubeSats for observing hard X-ray emission from solar flares is possible, for example, if a scintillation detector is installed on a CubeSat as a payload. The advantage is that a CubeSat is a relatively simple and inexpensive device, experiment preparation usually takes less time, requirements for equipment are less stringent, etc. However, when setting up an experiment on a CubeSat, many technical issues must be addressed that are already solved on "classical" satellites.

First, the amount of information that can be transmitted to Earth is limited. Most CubeSats use the VHF band for this purpose, which allows transmitting less than 1MB per day. This corresponds to approximately one orbit per day of monitoring measurements in several channels with a frequency of once per second. Naturally, one cannot expect that a solar flare will occur exactly during this orbit. One way to solve this problem is to control the time interval for which data needs to be transmitted. Internal memory can be installed on the CubeSat, to which the continuously operating detector records its readings. If this memory provides data storage for several weeks, then the researcher, knowing the time of the flare, can request the transmission of information specifically for this period via a command from Earth.

The problem with conducting continuous monitoring observations is not so acute if telemetry transmission from the CubeSat is provided not in the VHF but in the S-band. However, in any case, conducting continuous observations also requires providing power to the continuously operating detector.

Currently, continuous observations of the Sun in hard X-rays are conducted on many spacecraft. Typically, these experiments obtain time profiles of flares with approximately one-second resolution, and MSU CubeSats are no exception. Now the frame rate of monitoring on the satellite *Avion* has been reduced to 0.5 s. To provide even more detailed profiles (with millisecond resolution and even better), as well as multi-channel emission spectra on all CubeSats of the MSU constellation launched in 2023 (the *Avion*, *Monitor*-2, -3, -4, *UTMN*-2), another mode of recording information from detectors is provided — "event-by-event recording." The time of each interaction of a quantum or particle in the detector is recorded with microsecond accuracy, as well as the amplitude of scintillation at two points in time, allowing to precisely determine the type of particle and its energy. This essentially primary information is also expected to be downlinked for subsequent processing on Earth. Such information takes up much more space than monitoring data, so the activation of this channel should be carried out in trigger mode (for example, at the moment of sharp increase in count rates when the satellite is near the equator). At present, event-by-event recording from MSU CubeSats is used only in test mode for detector calibrations.

When registering X-ray radiation from solar flares, it is necessary to take into account not only the complex background conditions in near-Earth orbit but also the rotation of the spacecraft. Typically, small inexpensive CubeSats do not have systems that maintain stable orientation, and the spacecraft experiences rotation with a period that can range from several seconds to minutes. The CubeSat *Avion* in February 2024 had a rotation period of several minutes, which is evident from variations in count rates in trapped radiation regions, as well as from the readings of magnetometers that are part of the satellite's payload. Using the known data from the three-axis magnetometer, satellite coordinates, and the geomagnetic field model, it is possible to determine the directions of the CubeSat's axes, and consequently, the angle between the detector and the Sun, which is necessary for calculating the effective area of the detector at any point in time.

One cubesat operating in a near-Earth polar orbit at an altitude of ~550 km cannot provide continuous monitoring of the Sun. Firstly, due to the Earth's shadowing - for example, in February 2024 the satellite *Avion* was in the Earth's shadow for approximately one-third of the time. Secondly, observations are also impossible in areas of increased radiation both due to the background level and its variations. The satellite *Avion*, as well as other MSU cubesats with similar orbits, spend approximately 30 % of the time in radiation belts. Observations are possible at the equator (~50 % of the time), as well as in the polar cap regions (~20 % of the time), where the background is stable, albeit elevated. The problem of inability to conduct continuous observations due to both being in shadow and background conditions could be solved by using a constellation of cubesats positioned at different points in near-Earth space.

CONCLUSION

During the first months of operation of the satellites *Avion*, *Monitor*-2, -3, -4 and *UTMN*-2, launched into near-Earth polar orbit on 27.VI.2023, hard X-ray radiation with energy >30 keV was detected from nine solar flares. It should be noted that these cubesats were not specifically designed for solar research; their main tasks are related to space weather - monitoring radiation in near-Earth space, and astrophysical problems - detecting gamma-ray bursts. Nevertheless, the obtained time profiles of flares, consistent with data from *Konus-WIND*, STIX (*Solar Orbiter*) and other experiments, indicate the possibility of using such relatively simple nanosatellites for observing solar hard X-ray radiation.

All five cubesats of the MSU constellation are functioning normally, and monitoring observations are ongoing. Currently, optimization of detector settings (energy thresholds, time resolution of monitoring channels, etc.), development of the event-by-event recording mode, and the use of magnetometers to determine the satellite axis direction are being carried out. The table of registered flares is regularly updated.

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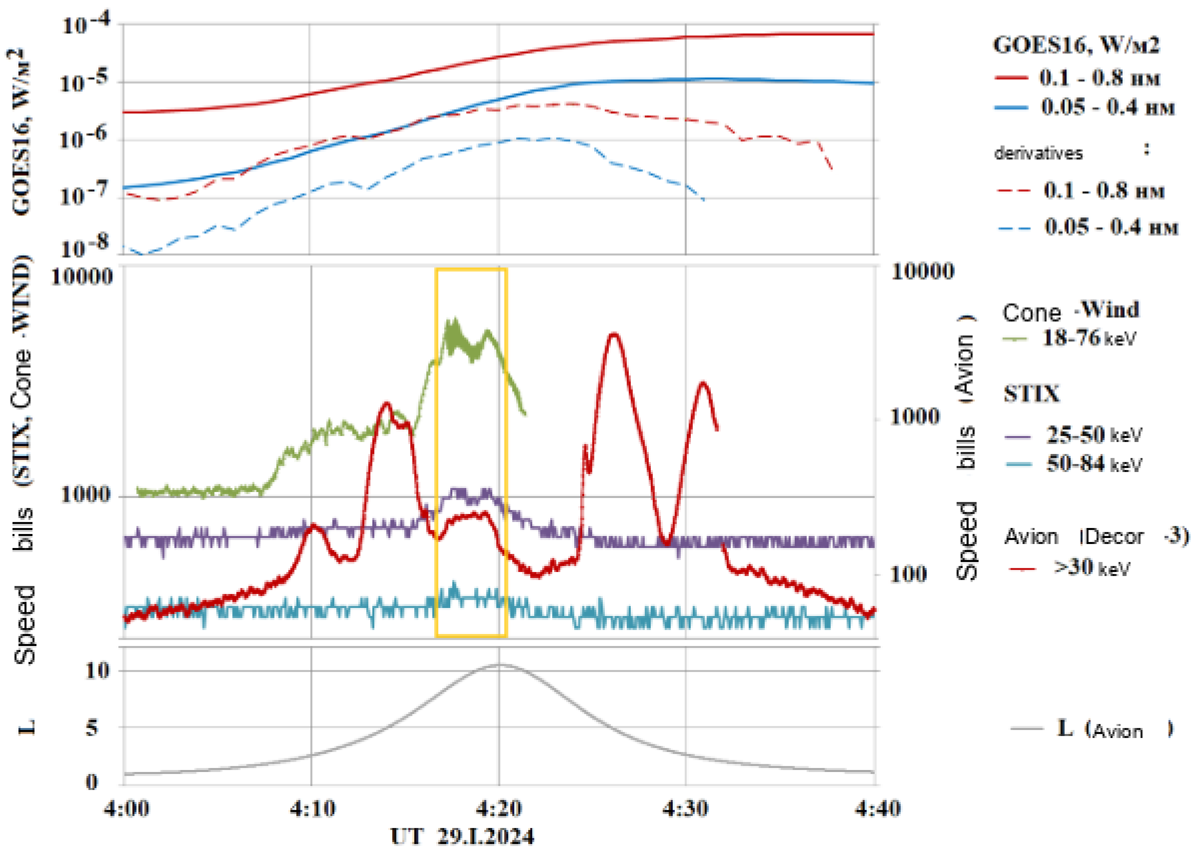
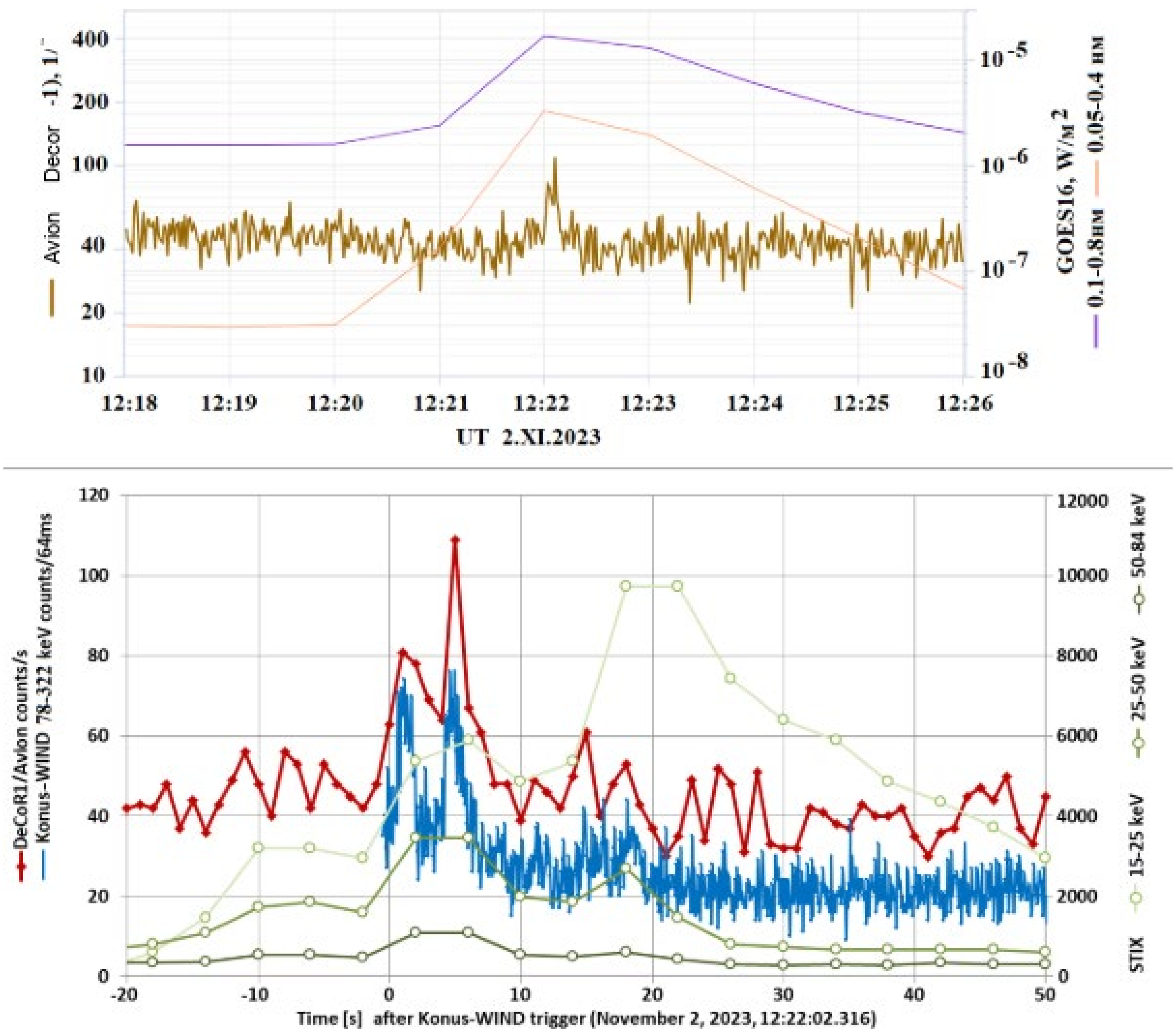

GOES16, W/м2
10-4
10-5
10-6
10-7
10-8
GOES16, W/м2
0.1 - 0.8 нм
0.05 - 0.4 нм
derivatives :
0.1 - 0.8 нм
0.05 - 0.4 нм
Speed bills (STIX, Cone -WIND)
10000
1000
Speed bills (Avion)
10000
1000
100
Cone -Wind
18-76 keV
STIX
25-50 keV
50-84 keV
Avion (Decor -3)
>30 keV
L
10
5
0
L (Avion)
4:00
4:10
4:20
4:30
4:40
UT 29.I.2024

Fig. 1.



Avion
Decor
400
200
100
40
20
10
10^-5
10^-6
10^-7
10^-8
GOES16, W/м2
0.1-0.8нм
0.05-0.4 нм
12:18
12:19
12:20
12:21
12:22
12:23
12:24
12:25
12:26
UT 2.XI.2023
DeCoR1/Avion counts/s
Konus-WIND 78-322 keV counts/64ms
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
50-84 keV
25-50 keV
15-25 keV
STIX
-20
-10
0
10
20
30
40
50
Time [s] after Konus-WIND trigger (November 2, 2023, 12:22:02.316)

Fig. 2.

FIGURE CAPTIONS

Fig. 1. Time profile of soft (*GOES*) and hard X-ray emission (*Avion* , *Konus-WIND* , STIX) during the flare on 29.I.2024 (start at 03:54 UT), as well as the McIlwain parameter *L* for the Avion cubesat during the flare.

Fig. 2. Time profile of soft (*GOES*) and hard X-ray emission (*Avion* , *Konus-WIND* , STIX) during the flare on 02.XI.2023 (start at 12:18 UT)