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The analysis of links between the characteristics of active regions on the Sun and X-flares classes M and X on the GOES scale

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Abstract

The analysis of links between speed and size of squares change of visible active regions at the Sun and their classification index with the generation of powerful solar flares of classes M and X according to Space Weather Prediction Center NOAA data is carried out. Measurements in 23 and 24 cycles of solar activity were processed. Results of the analysis and offer on algorithm for control by the biaxial targeting platform on the service module “Zvezda” of the Russian Segment of the International Space Station, where the GRIS device detectors unit is placed, are given.

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*Keywords:*Space experiment; International Space Station; solar flares; prediction; gamma and hard x-ray radiation; biaxial platform of targeting; active region; McIntosh classification.

1. Introduction

This analysis was carried out for the purpose of development of criteria for forecasting of solar flares and its application for the observation periods choice for period of operating the space experiment (SE) GRIS-FKI-1 onboard the Service Module "Zvezda" in the Russian Segment of the International Space Station. Information about this experiment is presented on TSNIIMASH web site[1].

Space experiment is intended for research of active non-stationary processes on the Sun, physical mechanisms and conditions of acceleration of electrons, protons and nucleus on various phases of solar flares progress. The scientific equipment, described in [2],is designed to measure fluxes and power spectra of gamma and hard x-ray

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radiation from the Sun in range of 50 keV – 200 MeV and register neutrons with energy of 30-200 MeV. The experimental data which are available so far were obtained in experiments of SMM/GRS, GRANAT/PHEBUS, RHESSI, GAMMA/GAMMA1, CGRO/EGRET, CORONAS-F/SONG and AVS-F, showed that hard x-ray and gamma radiation in most cases are present at flares of M - and X-classes on GOES scale. And hard energy gamma radiation with energy more than 60 MeV was registered only in flares of a class X.

As noted in the article [3], so far there are only four reliable events in which the line of π^0 decay and five events with neutrons emission was registered. It shows the significance of similar observations in future experiments. External conditions of its carrying out have very great influence on efficiency the GRIS-FKI-1experiment. First of all it is visibility of the Sun by scientific equipment and phases of a 11-year cycle of solar activity (SA). Generally high-energy events were registered near a maximum of the solar activity.

2. Conditions of carrying out GRIS-FKI-1 experiment

The block of detectors of the scientific equipment is planned to place on the biaxial platform of targeting (BPT) outside of the module. On Fig. 1 the installation option is shown. The carried-out calculations of visibility of the Sun in field of view and simultaneous missing of ISS design elements in it showed that in any stationary position of the block the exposition won't exceed 6-7% of observation time. When "The mode of tracking the Sun" (the active mode, with targeting of an axis of the block at the center of a solar disk) is switched on, it will increase to 40-45%. But when using BPT it is necessary to consider restrictions on a functioning resource in the mode of tracking and possibility of installation on BPT at the same time of two other devices with various observation programs.

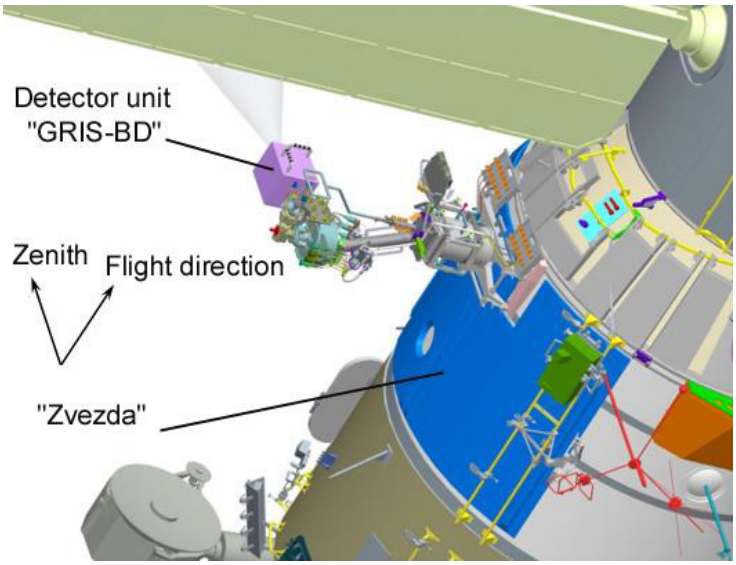

Fig. 1. Option of placement of the detectors block "GRIS-BD" on BPT

Switching of the modes can be carried out by commands from Earth according to the chosen algorithm. Carrying out of space experiment (SE) is planned in 2019-2021.

On Fig. 2 the 23rd and 24th cycles of solar activity are presented in the form of monthly average numbers of solar spots, from NOAA web site [4]. The forecast of further behavior of the 24th cycle, made by NOAA [5], is given on Fig. 3. It is seen that in 2019-2021 there will be a minimum of SA and, perhaps, the growth phase of the 25th cycle will begin. Therefore, during measurements the number of flares will be small and it is very important to predict with high probability the temporary periods of solar flares of M - and X-classes appearance.

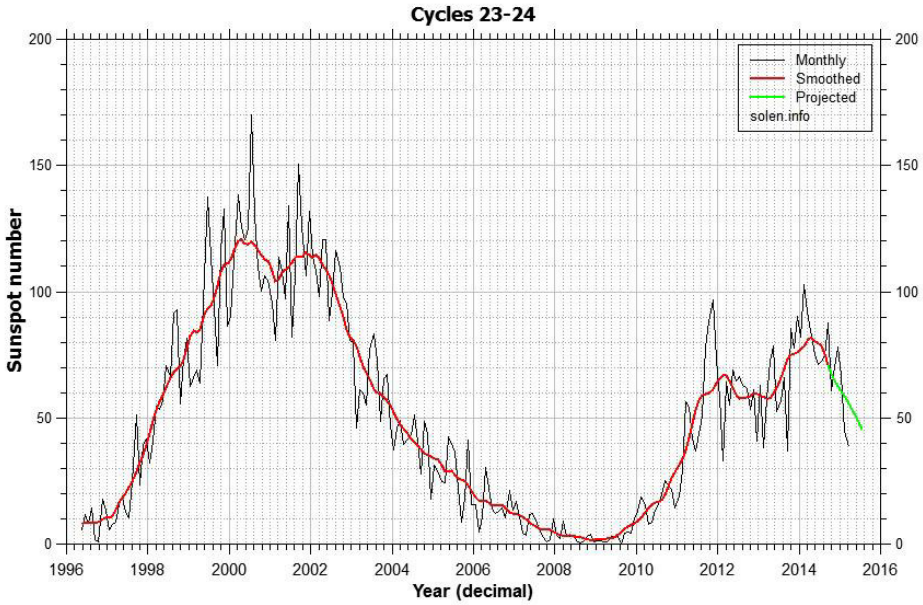

Fig. 2. Solar activity in the 23rd and 24th cycles

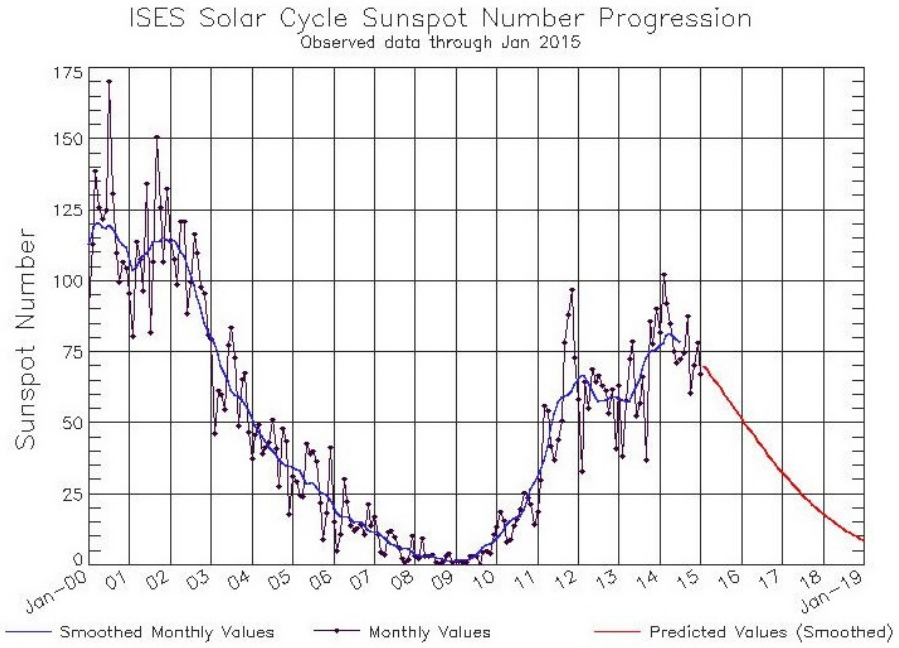

Fig. 3. Solar activity forecast for 24th cycle

3. Data Analysis and results

Now and, we hope, further on website www.noaa.gov/products/goes-x-ray-flux Current Solar Data (CSD) where in the real time are presented measured by GOES instruments the intensity of fluxes of soft x-ray radiation in range

of 1-8 Å will be accessible. These data can be used for the operational forecast of flare events behavior upon their appearance. For carrying out the analysis the NOAA databases on the site www.swpc.noaa.gov/products, namely Daily Solar Data (DSD.txt) and Solar Region Summary (SRS.txt) were used.

Characteristics of active regions (AR) on a visible disk of the Sun are presented in data of SRS.txt, namely: number of AR, the area, number of spots, coordinates, magnetic type and a McIntosh Solar Group Classification index, proposed by McIntosh in the paper [6], for AR's. Data for the last day are available 0.30 UT next days and can be used for the forecast of flare activity for the next 1-3 days.

DSD.txt included daily data on intensity of background radiation, number of flares C-, M- and H-classes, radio emission fluxes with the wavelength of 10,7 cm, number of solar spots and their total areas for AR's. Space Weather Prediction Center (SWPC) daily forms forecast of space weather, including flare activity for the next 1-3 days. At the forecast the probabilities of flare events calculated by results of processing of experimental data for active areas with various classification indexes are used. It is considered that in time of an event are distributed statistically under Poisson's law. On www.swpc.noaa.gov/products there are results of predictions for M-class flares production averaged by years during 1986-2012. Results are yielded in comparison with meteorological forecast. Unfortunately, success of the forecast of emergence of flashes of M- and H-classes, as shown on [7], is small.

In the period of low solar activity success of the forecast (Forecast skill) decreases, and to use it for BPT control is inefficiently. We made attempts to find additional forerunners and DSD.txt data from NOAA archive for 1996-2013 for this purpose were analyzed. It was pointed out, that in a significant number of M- and H-classes flares they produced by groups and the following registration algorithm is offered:

"The mode of tracking the Sun" (the active mode) of BPT is switch on the next calendar day after production of a M - or the X-class solar event according to CSD and it works within a two days. If during this period we have M- or the H-class event this mode will active for next two days and so on. If events of these classes within two day aren't registered, the active mode is terminated.

According to the solar activity forecast, expressed in number of solar spots, the estimated period of GRIS-FKI-1 experiment activity will be similar to the next temporary periods of the 23rd and 24th cycles SA: 1997, 2006-2007, 2010. Data from site [8], on M- and H-classes solar flares for these years, are presented in Tables 1-4.

At application of the algorithm, offered above, it could be registered 5 flares in the year that makes about 45% of their full quantity at 18 observation days. It should be noted that the real registered number of events will be less according to coefficient of visibility of the Sun.

For increase in efficiency of registration of M - and X-classes events, the analysis of correlations between some characteristics of active regions with probability of flares production was carried out. In work (6) offered classification of active regions on the Sun in three parameters:

- Z — modified Zurich class;
- P — a penumbra of the biggest spot;
- C — distribution of solar spots in active region.

Z is determined by existence of penumbra, to their distribution and group of spots length in its limits. P is defined by a combination of type, the size and symmetry of a penumbra and solar spots in its limits.

According to McIntosh classification it's possibly to describe 60 various types of groups of solar spots in the Active Region (AR). Kildah [9] identified, by results of the data analysis for 1969-1976, the most productive types of the AR generating flares of M- and X-classes. In production size they settle down in the following sequence: Ekc, Fki, Ekc, Eki, Dkc, Dai. Thus the average number of M-class flares from the Dai and Fki areas in 24 hours of their existence will be 0,18 and 2,26 respectively.

Depending on the period of SA, the appearance ratio for the different types of AR's changes. If SA decreases, the partion of C- and D-classes of AR's increases. Therefore it is reasonable to watch for appearance of productive types F, E of AR on a visible disk of the Sun and at their appearance to switch on BPT active mode. At such algorithm the probability of registration will increase to 65%. at 40 days of observation in a year.

When tracking for type D AR's it is possible to increase probability of registration up to 76% at 100-110 days of observation in a year, but this is represented unreal.

For the purpose of further forecast success increasing the analysis of AR's behavior dynamics, namely, speeds of area change and number of solar spots in 1-2 days before to generation of M- or X-class flare, change magnetic and McIntosh type was carried out. Also initial coordinates and duration of presence AR's on a Sun disk and time from appearance of AR's to first flare production by this AR's were analyzed. The behavior of 70 identified AR's making flares in 1997-2012 was considered. Results of the carried-out analysis don't indicate existence of correlations between change of the area and number of solar spots with M - and the X-class flares generation. Magnetic types of the productive AR's in the periods of low solar activity are simpler, than during the periods of high activity. Generally they have types — β or βγ. AR's square and number of spots in AR's is less too. The productive AR can arise on the visible part of solar disk (New) or to arrive already created because of a limb (Limb). From the data in Tables 1-4 follows that over 95% of the productive AR arrive because of a limb. In the same place intervals T in days from appearance of AR to first flare production by this AR are presented. It is visible that intervals as for the AR's arriving in a limb, and for the AR's, arising on a disk, can be any within 1-12 days.

Table 1.M- and X- classes flares in 1997 year

Data (mm.dd)	Number of AR	Limb/New	Flares	T, days	McIntosh Class
05. 21	8040	Limb	M1.3	6	Dsi/Cso
08. 29	8076	Limb	M1.4	5	Dsi/Cso
09. 02	8076	Limb	M1.0	9	Fsi/Esi
09. 08	8083	Limb	M1.0	6	Dai/Dao
09. 17	8084	Limb	M1.0; M1.7	12	Eao/Dao
09. 24	8088	Limb	M3.0; M5.9	4	Dao/Cso
11. 03	8100	Limb	M1.0; M1.4	7	Eki/Eai
11. 04	8100	Limb	M1.3; M4.1; X2.1	8	Fks/Eki
11. 06	8100	Limb	X9.4	10	Fks/Fks
11. 26	8113	Limb	M2.0	1	Hax/ -
11. 28	8113	Limb	M6.8	3	Eko/Eko
11. 29	8113	Limb	M4.4	4	Eko/Eko
12. 01	8113	Limb	M1.2	6	Fsc/Eho

Table 2. M- and X- classes flares in 2006 year

Data (mm.dd)	Number of AR	Limb/New	Flares	T, days	McIntosh Class
04.06	10865	Limb	M1.4; M1.2	10	Eki/Dkc
04.26	10875	Limb	M1.3	4	Dki/Dkc
04.27	10875	Limb	M7.9	5	D*ki/Dki*
07.06	10898	Limb	M2.5	9	Cki/Dki
12.06	10930	Limb	M1.3; M6.0;M3.5; X6.5	1	Dko/---
12.07	10930	Limb	M2.1	2	Dkc/Dko
12.13	10930	Limb	X3.4	8	Dki/Dki
12.14	10930	Limb	X1.5	9	Dki/Dki

Table 3. M- and X- classes flares in 2007 year

Data (mm.dd)	Number of AR	Limb/New	Flares	T, days	McIntosh Class
06.02	10960	Limb	M2.9; M1.0	1	Dki/---
06.03	10960	Limb	M2.4; M7.0;M4.5	2	Fkc/Dki
06.04	10960	Limb	M8.9	3	Fkc/Fkc
06.09	10960	Limb	M1.0	8	Esc/Esi

Table 4. M- and X- classes flares in 2010 year

Data (mm.dd)	Number of AR	Limb/New	Flares	T, days	McIntosh Class
01.20	11041	Limb	M1.8; M3.4	1	Cso/---
02.06	11045	Limb	M1.3; M2.9	1	Dkc/ Cso
02.07	11045	Limb	M6.4	2	Dkc/Dkc
02.08	11045	Limb	M4.0;M1.1;M1.0	3	Fkc/Dkc
02.12	11045	Limb	M1.1	7	Fsi/Fai
05.05	11069	Limb	M1.2	2	Dai/Dai
06.13	11079	New	M1.0	5	Bxo/Bxo

4. Conclusion

From the carried-out analysis of M- and H-classes solar flares and their correlations with characteristics of the productive AR's for 1-2 day forecasting for period of operating GRI-FKI-1, it is possible to make the following main conclusions:

- M- and H-classes flares even during the periods of low solar activity generally arise not one by one, and groups;
- the most part of flares are produced by AR's arriving because of a limb;
- during the studied periods of low SA of flares are produced by AR's of F, E, D types on McIntosh classification;
- correlations between speeds of change of the AR's areas and number of solar spots in AR's with production by this AR flares aren't found.

For control of BPT operating mode for period of operating GRI-FKI-1 the following algorithm of switching on the active mode is offered:

- Active mode for BPT is switched on after appearance in SRS AR F-, E- types for all the time of existing this types in characteristics for AR;
- Active mode for BPT is switched on after production of a M- or the X-class solar event according to CSD and it works within a two days, if in this period there are new M- or the X-class solar flares, in this case active mode lasts on the following two days.

In the period of low solar activity at such control of BPT it is possible to register up to 65% of M- or X-classes flares at 10-12% of observation time in a year.

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