INFO #: 16800840 **University of New Hampshire**
Mark McConnell

NB 05/11/2006
12:00 AM PT
Z

SHIP VIA: **Ariel mark.mcconnell@unh.edu**
Ariel

FILLED ON: 05/02/2006

Infotrieve, Inc.
11755 Wilshire Blvd
19th Floor
Los Angeles, CA 90025
Phone (310) 445-3001 x0 or 800-422-4633 x0
Fax 310-445-3003

Web DB Article Delivery

NB 05/11/2006
12:00 AM PT
Z

SHIP TO : 115377 / 869483

University of New Hampshire
Mark McConnell

Space Science Center
Morse Hall, Rm. 312, 39 College Road
Durham, NH 03824 United States
United States

Please contact us if you have questions or comments regarding this article.
Email: service@infotrieve.com Phone: (800) 422-4633

ARTICLE INFORMATION

CUSTOMER INFO
PHONE: 603-862-2047
FAX:
TEAM: T5
COURIER:

ARIEL: mark.mcconnell@unh.edu

NOTES:

00380946
SOLAR SYSTEM RESEARCH
40(2):93-103 2006

Polarization, temporal, and spectral parameters of solar flare hard X-rays

CCD	4100
SHIP VIA	Ariel mark.mcconnell@unh.edu
ORDER #	
BILLING REF	
ORDERED ON	05/02/2006
FILLED ON	05/02/2006
NEED BY	05/11/2006
ATTENTION	Mark McConnell
INFO #	16800840

ISSN 0038-0946, Solar System Research, 2006, Vol. 40, No. 2, pp. 93–103. © Pleiades Publishing, Inc., 2006.
Original Russian Text © I.A. Zhitnik, Yu.I. Logachev, A.V. Bogomolov, Yu.I. Denisov, S.S. Kavanosyan, S.N. Kuznetsov, O.V. Morozov, I.N. Myagkova, S.I. Svertilov, A.P. Ignat'ev, S.N. Oparin, A.A. Pertsov, I.P. Tindo, 2006, published in Astronomicheskii Vestnik, 2006, Vol. 40, No. 2, pp. 108–119.

Polarization, Temporal, and Spectral Parameters of Solar Flare Hard X-rays as Measured by the SPR-N Instrument Onboard the *CORONAS-F* Satellite

I. A. Zhitnik[a], Yu. I. Logachev[b], A. V. Bogomolov[b], Yu. I. Denisov[b], S. S. Kavanosyan[b], S. N. Kuznetsov[b], O. V. Morozov[b], I. N. Myagkova[b], S. I. Svertilov[b], A. P. Ignat'ev[a], S. N. Oparin[a], A. A. Pertsov[a], and I. P. Tindo[a†]

[a]*Lebedev Institute of Physics, Russian Academy of Sciences, Leninskii pr. 53, Moscow, 117924 Russia*
[b]*Skobeltsyn Research Institute of Nuclear Physics, Moscow State University, Vorob'evy gory, Moscow, 119899 Russia*

Received April 5, 2005

Abstract—The SPR-N polarimeter onboard the *CORONAS-F* satellite allows the X-ray polarization degree to be measured in energy ranges of 20–40, 40–60, and 60–100 keV. To measure the polarization, the method based on the Thompson scattering of solar X-ray photons in beryllium plates was used; the scattered photons were detected with a system of six CsI(Na) scintillation sensors. During the observation period from August 2001 to January 2005, the SPR-N instrument detected the hard X-rays of more than 90 solar flares. The October 29, 2003, event showed a significant polarization degree exceeding 70% in channels of $E = 40$–60 and 60–100 keV and about 50% in the 20- to 40-keV channel. The time profile of the polarization degree and the projection of the polarization plane onto the solar disk were determined. For 25 events, the upper limits of the part of polarized X-rays were estimated at 8 to 40%. For all the flares detected, time profiles (with a resolution of up to 4 s), hard X-ray radiation fluxes, and spectral index estimates were obtained.

PACS numbers: 96.60 ge

DOI: 10.1134/S003809460602002X

INTRODUCTION

When flares occur on the Sun, an increase in the hard X-rays is sometimes observed, which can be interpreted as a consequence of the particle acceleration in the solar atmosphere (Stepanov, 1982; Dennis, 1985). The study of parameters of flare-associated hard X-ray bursts is of doubtless interest for understanding the processes of particle acceleration in flares and for examining the nonflare acceleration mechanisms which have been under discussion lately (Kahler et al., 1988; 1994).

The polarization degree of solar flare hard X-rays (~10–100 keV) is the most important parameter allowing one to estimate the direction of accelerated electron fluxes in the solar atmosphere (Skrinnikov, 1985; Rausariya and Tindo, 1989). A very high polarization degree may indicate a strongly anisotropic electron beam moving inside the chromosphere along the magnetic field lines, which in turn requires extremely high electric currents and strong magnetic fields. Theoretical models predict the polarization degree of the solar flare hard X-rays ranging in very wide limits: from several percent in the thermal and nonthermal stationary models to tens of percent in the nonthermal models with the impulsive injection of an electron beam (Skrinnikov, 1985; Guzman et al., 1996; Rausariya and Tindo, 1989). As for the experimental data, so far the polarization degree has been measured only for several flares in a relatively soft X-ray range (at a wavelength of about 0.8 Å) (Zhitnik et al., 1989; Tindo et al., 1971; Tindo et al., 1972), and these measurements demonstrate a considerable spread from 2–3% to 20–40%.

To measure the polarization of the solar flare hard X-rays, the *CORONAS-F* satellite (the orbital parameters are altitude, 507 ± 21 km; inclination, 82.5°; and orbital period, 94.5 min) has the SPR-N instrument onboard (Bogomolov et al., 2003a). This instrument allows the polarization degree of X-ray radiation to be determined in the following ranges of energy of the detected photons $E_\gamma = 20$–40, 40–60, and 60–100 keV. The method of measurements is based on the Thompson scattering of solar photons in beryllium plates. Five plates of metallic beryllium are mounted inside a hollow hexagonal prism. Six scintillation detectors are symmetrically mounted on the prism faces around the scatterer. A phoswich (a CsI(Na)/plastic scintillator based on polystyrene) is used in the detectors to eliminate the detection of charged particles. The geometric area of each detector is about 8 cm^2; with regard to the absorption in protective materials and the efficiency of scattering and registration in the detector, the effective area varies from ~0.3 cm^2 to ~1.5 cm^2 at $E_\gamma = 20$ and 100 keV, respectively.

†Deceased.

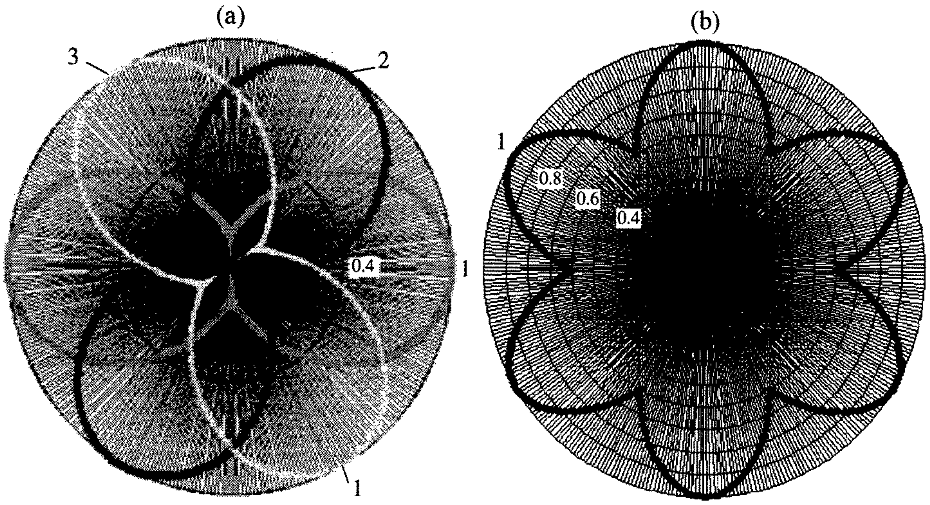

Fig. 1. The diagrams characterizing the relative outputs of the polarization detectors (a) and the polarization degree derived from these outputs. (b) They are shown in dependence on the orientation of the polarization plane for the case when the normally (to the polarimetry surface) incident radiation is fully polarized (100%). The angular dependences of count rates of the detectors for the 100% polarization (the maximal count rate was assumed to be 1). The dependence of the polarization degree $Q = (N_{max} - N_{min})/(N_{max} + N_{min})$ on a polarization-plane angle for the fully polarized radiation; the first detector pair; the second detector pair; the third detector pair.

Since, for nonpolarized radiation, the probabilities of its scattering at different angles relative to the initial direction of the photon motion are identical, it will be scattered in an azimuthally symmetric way, and all the detectors must detect the same intensity in this case. For plane-polarized radiation, most photons are scattered normally to the polarization plane. If the photons are assumed to fall mostly normally to the scattering plane when the instrument is directed to the Sun, the plane-polarized radiation will evidently be scattered in the beryllium plates mainly along their plane. In this case, pairs of opposite detectors correspond to polarization planes turned by 120° relative to each other. Since photon scattering is azimuthally anisotropic for plane-polarized radiation, the counts must be different in different detector pairs: the maximum counts will be in the detectors that are closest (within ±60°) to the plane normal to the polarization plane. Thus, the difference in the count rates of the detectors allows one to estimate the polarization degree P_{meas} of the detected radiation and, in general, the angular displacement of the polarization plane φ with respect to the detector pair.

To diminish the influence of systematic effects, it was expected that the beryllium scatterer would be turned together with the detectors by ±60° relative to the direction to the Sun during observations. In this case, if the detected radiation is polarized, the difference in the detector outputs must be the same regardless which detector pair is closer to the polarization plane.

To determine the part of the polarized radiation P_{meas} and the polarization plane orientation from the count rates N_i in the polarization detectors, the contributions of each detector to the total count rate of all detectors (in percent) were previously calculated for all parts of polarized radiation and all orientations of the polarization plane. In order to retrieve P_{meas} from the measured N_i values, the Thompson scattering in beryllium plates was modeled for normally incident plane-polarized radiation. For the assumed polarization of the incident radiation P_0 (which was chosen between 0 and 100%), the quantities $N_i/\sum_{i=1}^{3} N_i$ were calculated as functions of angle φ. These quantities characterize the part of the scattered polarized radiation coming to a given detector pair relative to the total incident flux (see Fig. 1a). The resulting functions allow us to solve the inverse problem, i.e., to find the polarization degree P_{meas} of the incident radiation and the angle φ from the quantities measured (see Fig. 1b). Thus, by solving the inverse problem, the part of polarized radiation and the orientation of the polarization plane can be determined from the given count rates of the polarization detectors.

The instrument is also provided with a special "patrol" detector for measuring the time profile of the X-ray intensity with a fine resolution in the 15–100 keV energy range and, consequently, for estimating the flux and the spectrum hardness in this energy range. It is a pencil-beam phoswich detector: a CsI(Na)/plastic scintillator (the thickness of the CsI(Na) crystal is 3 cm and the effective area is ~1 cm^2 at the energy of the detected photons $E_\gamma = 40$ keV).

The design of the SPR-N instrument and its operating principle are described in detail by Bogomolov et al. (2003a).

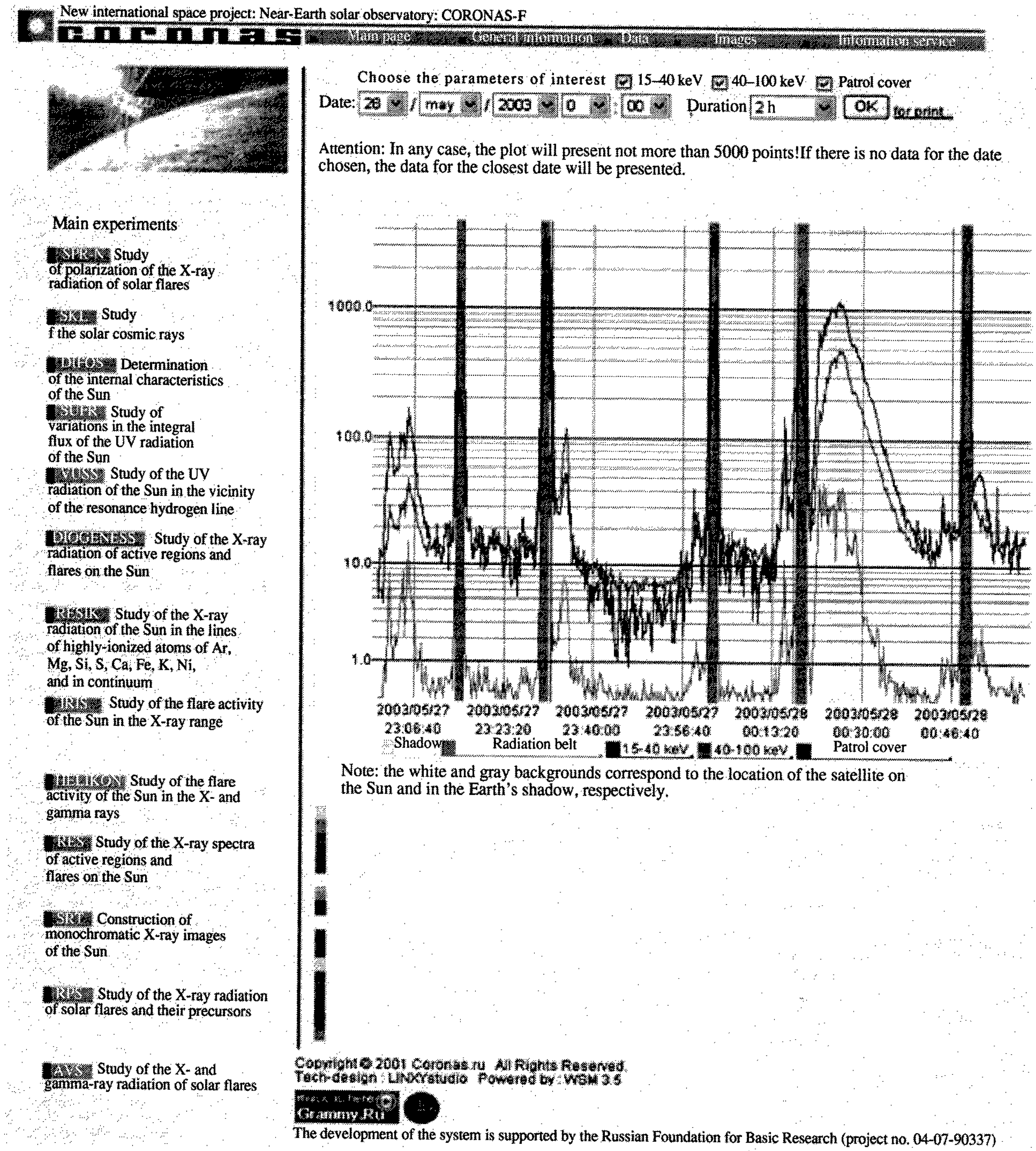

Fig. 2. The web page of the site http://www.coronas.ru displaying the data from the patrol detector of the SPR-N instrument.

THE DATABASE OF THE SPR-N EXPERIMENT

During the period of its operation from August 2001 to December 2005, the SPR-N instrument performed an almost continuous monitoring of solar activity with the usage of the patrol detector covering the energy ranges from 15 to 40 and from 40 to 100 keV. The hard X-ray radiation from more than 90 solar flares was recorded during this period. For all the events, time profiles with a resolution of less than 4 s were built. The results of solar-flare measurements with the SPR-N instrument in 2001-2002 are presented in the papers by Bogomolov et al. (2003a, 2003b).

The information from the patrol detector of the SPR-N instrument is presented at the site http://www.coronas.ru in the form of time profiles of the X-ray fluxes (cm^{-2} s^{-1}) in the 15- to 40- and 40- to 100-keV energy channels. The appearance of one of the web pages is shown in Fig. 2. A user can choose the time interval of interest by indicating the starting moment and the interval duration (30 min, 1 h, 2 h, or the whole session (approximately half a day)). The figure also displays the count rates (s^{-1}) from the protective cover of the plastic scintillator (mainly due to charged particles). The intervals where the count rate exceeds 1000 s^{-1} (presumably, the regions of radiation belts) and the shadow periods (the periods when the Sun was screened by the Earth) are indicated with colors. Figure 2 demonstrates the period when no shadow was observed.

Figure 2 clearly shows that the background conditions for flare observations are most favorable at the equator (the background count rate is about 3.0 and 0.5 s^{-1} in the 15- to 40- and 40- to 100-keV channels, respectively). In the polar-cap regions (where the count rates are an order of magnitude higher), relatively strong flares (of M and X classes) can be observed as well. A significant part of the observation period corresponds to the time when the satellite passed through the radiation-belt regions. However, for the strongest flares of X class, the count rates of the flare radiation can be an order of magnitude higher than the background counting in the outer radiation belt. As an example, the period when the X3.6 class flare (May 28, 2003; maximum at ~0^h27^m UT) was observed is presented in Fig. 2. The weakest flares, the hard X-ray radiation of which was detected with the SPR-N patrol detector, fall into the C2.5 class (for example, the flare of October 6, 2004, at ~18^h30^m UT).

In addition to the SPR-N data, the description of the instrument, its photos, and other useful information are present at the web site http://www.coronas.ru. A place is also reserved at the site for information from other instruments onboard the *CORONAS-F* satellite (the left part of Fig. 2). Among the data already available, there are fluxes of charged particles from the MKL instrument and a database of the solar flares recorded by the SONG instrument.

The X-ray fluxes measured in the ranges 15–40 and 40–100 keV during the five most powerful flares (on August 25, 2001; October 28, October 29, and November 4, 2003; and January 20, 2005) of the entire operation period of the SPR-N instrument are plotted in Fig. 3. The same figure also displays the soft X-ray fluxes measured at wavelengths of 1–8 Å and 0.5–4 Å by the *Geostationary Operational Environmental Satellites* (*GOES*). These data are available from the web site of the Space Environment Center at http://sec.noaa.gov.

RESULTS OF THE POLARIZATION MEASUREMENTS

The polarization degree was estimated under the assumption that the total hard radiation of the solar flare is the sum of a certain portion of photons polarized in the same plane and the remained portion of photons polarized isotropically.

About 25 solar events that induced a signal in the polarization detectors sufficient for the estimation of the polarization degree have been observed by the SPR-N instrument since August 2001. For most of these flares, only the upper limits of the polarized radiation part could be evaluated; they were found to range from ~8% to ~40%.

The most interesting measurements of polarization of the solar hard X-rays were obtained during the extreme events in October–November 2003 (Veselovsky et al., 2004). The last ten days of October and early November 2003 were marked by an increase in solar-flare activity. Nine flares of X class occurred on the Sun during this period. The SPR-N polarimeter recorded six of them, including three of the four strongest ones. The measured polarization of hard X-rays (HXR) from the flares of October 28, 2003 (X17/4B), October 29, 2003 (X10/2B), and November 4, 2003 (X28/4B), is presented below. All these flares had the same source: active region 0486, which was almost in the center of the solar disk (S15W02) on October 28 and 29 and at the western edge of the limb (S19W83) on November 4. The *CORONAS-F* data on the gamma-ray radiation (up to 100 MeV) of these flares are described by Veselovsky et al. (2004). On October 29, 2003, the *CORONAS-F* spacecraft was near the geomagnetic equator, where the background conditions are the best. The event of October 28, 2003, was observed when the satellite was passing through the polar cap. For the event of November 4, 2003, results were obtained only for the early stage of the flux increase, because the satellite crossed the radiation belts during the main stage of the flux increase.

During these three flares, the polarization detectors recorded a notable increase in the count rate above the background. The latter was determined from the data obtained in the previous orbits at the points with geomagnetic coordinates closest to those corresponding to the moments of the flare detection. To diminish the statistical error, the time profiles were smoothed with the moving average method for five consequent exposures. For each consequent 14-second interval, the data were accumulated over 4 s; i.e., the exposure was 4 s with a polling rate of $4/14 \approx 0.28$. The polarization measurements for the flare of October 29, 2003, processed in such a way are shown in Fig. 4 together with the data from the patrol detector.

Three detectors located 120° apart were operating during the flares. To accurately estimate the polarization degree, the systematic spread in the polarization detector outputs must be taken into account. The in-flight calibration of the counters by light-emitting diodes, as well as the invariable background in the geomagnetic equator region, show a stability of their thresholds within several percent. Nevertheless, in the same energy ranges, the count rates can differ in different polarization detectors (see, for example, Fig. 4, which displays the count rates of polarization detectors

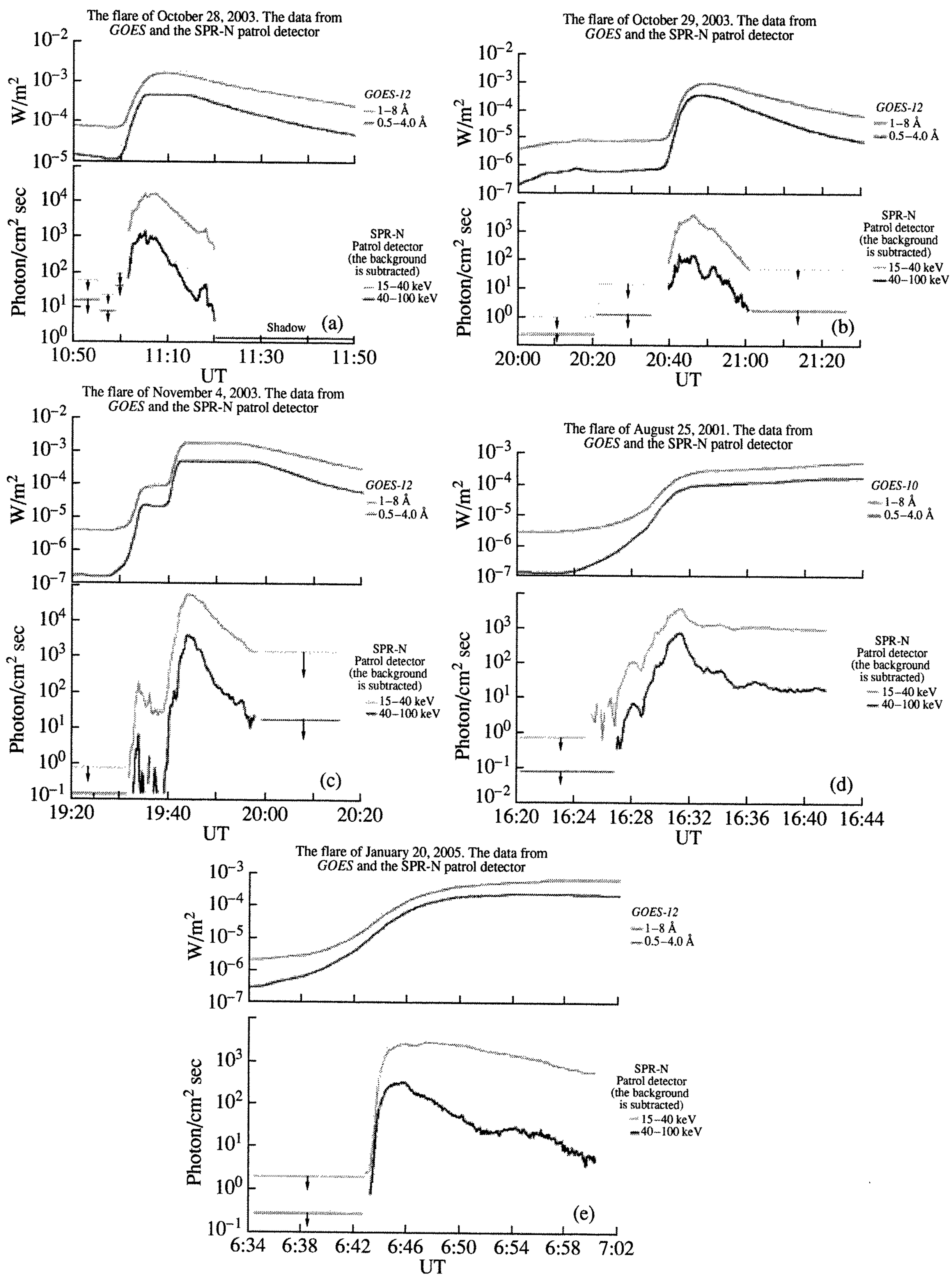

Fig. 3. The time profiles of the X-ray fluxes measured by the SPR-N instrument (channels of 15–40 and 40–100 keV) onboard the *CORONAS-F* satellite and by the *GOES* satellites (the data from the site http://sec.noaa.gov) (channels of 1–8 and 0.5–4 Å) during five strong flares in 2001–2005: (a) August 25, 2001; (b) October 28, 2003; (c) October 29, 2003; (d) November 4, 2003; (e) January 20, 2005.

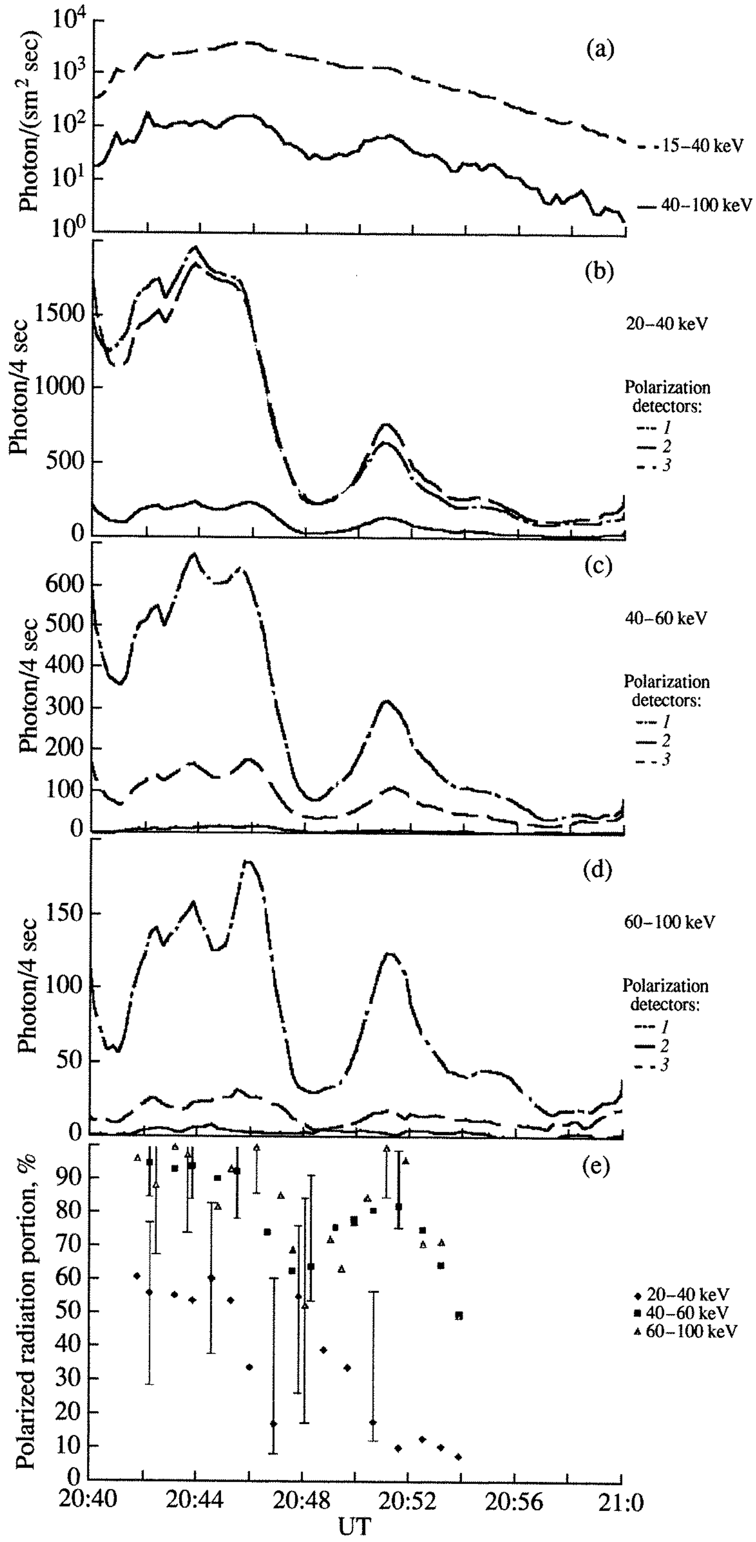

Fig. 4. The SPR-N data for the flare of October 29, 2003 (20:40–21:00 UT) obtained with the patrol detector (the upper curve is for the 15–40 keV channel; the lower one is for the 40–100 keV channel) (a) and with the polarization detectors in the channels 20–40 (b), 40–60 (c), 60–100 keV (d). In the plots (b-d), numbers *1*, *2*, and *3* indicate the group of polarization detectors. Plot (e) presents the time dependence of the portion of polarized radiation.

during the flare of October 29, 2003). This difference can be caused by the different efficiency of polarization detectors and different noise levels in their photomultipliers, as well as by the fact that the detectors are actually exposed to different X-ray fluxes. As mentioned above, in the case of solar radiation, this effect can be caused by strong polarization. If the background is measured near the geomagnetic equator and at low or middle latitudes, this effect can be induced by the X-ray radiation of the atmosphere, relative to which the polarization detectors can be differently directed at different moments and, correspondingly, detect atmospheric photons with different effective areas. If the measurements are fulfilled near the polar caps, in precipitation regions, and in radiation-belt offsets (in the radiation belts themselves, the detectors were, as a rule, overloaded, and their outputs were unreliable), this effect can be explained by the fact that the detectors are turned by different angles with respect to the constructive elements of the satellite devices, in which the secondary bremsstrahlung radiation is most efficiently generated by high-energy electrons.

Nevertheless, to determine the polarization degree of the recorded solar-flare radiation more precisely, we should eliminate the spread caused by different efficiencies of the polarization detectors in their outputs. To do this, we selected two groups of outputs. The first group included the outputs during several solar events, when the increase in the count rates of polarization detectors was statistically most representative. The second group contained the measurements at the geomagnetic equator and in low- and middle-latitude regions, that is, at parts of the orbit where the latitude variations in the count rate are clearly pronounced. It was also assumed that, during the quite magnetic epochs, the atmospheric contribution to the latitude radiation variations is insignificant and caused mainly by the X- and gamma-ray quanta locally formed in the material of the satellite due to interactions of galactic cosmic rays. The local gamma rays are isotropic and, consequently, the most appropriate for testing the detectors in terms of comparison of their efficiency.

Figure 5 shows diagrams displaying the ratios of the count rates for different pairs of polarization detectors versus their loading for the two groups of measurements. The figure shows that the count rates in polarization detectors nos. 1 and 3 are usually higher than those in detector no. 2 in all energy channels. This difference in the count rate of detectors is likely to have an instrumental cause. It can be explained by the difference in dispersion and, for the 20- to 40-keV channel, also by different noise levels in individual photomultipliers. During the preflight calibrations and the experiment itself, the photomultiplier amplification factors were adjusted by fine tuning of the supply voltage of the photomultipliers. As a result, the supply voltage differed for different photomultipliers. Note that the supply voltage mostly determines the photomultiplier noise levels and their dispersion, which strongly affects the energy resolution of the detector and, consequently, its response function and efficiency.

It is seen from Fig. 5 that the additional count rates in detector nos. 1 and 3 relative to those in detector no. 2 are independent of the total loading of the detectors, if the points associated with the measurements during the flare of October 29, 2003, are excluded. The spread of the ratios of the corresponding count rates N_1/N_2 and N_3/N_2 has both statistical and systematic (methodical) features. The statistical spread is mostly observed for weak loadings; as a rule, these are the background measurements, the so-called latitude trend. The spread at relatively large loadings during the solar flares can be caused by the dependence of the detector efficiencies on the photon energy, which leads to the dependence of the additional count rates on the hardness of the radiation spectrum. However, the diagrams analogous to those shown in Fig. 5, which were built for the additional count rates versus spectral hardness, did not reveal any correlation between the parameters N_1/N_2 and N_3/N_2 and the spectral hardness (the latter was described by the ratio of the count rate in the patrol detector channels of 15–40 and 40–100 keV). Moreover, as Fig. 5 shows, a probable systematic spread of the N_1/N_2 and N_3/N_2 values (except the measurements during the flare of October 29, 2003) is within the limits of their statistical spread. Thus, the statistical spread of the N_1/N_2 and N_3/N_2 values in the diagrams of Fig. 5 can be chosen as a measure of the error in normalizing coefficients, which should be used in equalizing the outputs of individual polarization detectors. The presence of the polarization component can be considered to be reliable if the N_1/N_2 and N_3/N_2 ratios exceed the 3σ spread level, which is shown for all energy channels in Fig. 5.

As seen from Fig. 5, for the part of the measurements related to the flare of October 29, 2003, the N_1/N_2 ratio exceeds the 3σ level in all energy channels: it is equal to ~4σ, ~10σ, and ~5σ in the channels 20–40 keV, 40–60 keV, and 60–100 keV, respectively. Moreover, the points for which the N_1/N_2 ratio is within the 3σ level or exceeds it slightly (less than 5σ in the 20- to 40-keV channel) correspond to the final—thermal—stage of the flare, when the X-ray radiation is unlikely to be polarized. At the same time, the points for which the N_1/N_2 ratio considerably exceeds the 3σ level correspond either to the onset of the flare or to the individual maximums of intensity, i.e., to the stages when the polarized radiation can, in principle, be observed in (Tindo et al., 1971). The other reason for considering the polarization of the recorded radiation as a cause of the fact that a substantial part of the measurements during the flare of October 29, 2003, falls out of the statistical spread level is the behavior of the N_3/N_2 ratio during these measurements. As follows from the figure, for the flare of October 29, 2003, this ratio is significantly smaller than the N_1/N_2 ratio, although it somewhat exceeds the 3σ level (~4σ in the channels 20–40 and 40–60 keV). However, for other measurements (related both to latitude variations and to other flares and a ther-

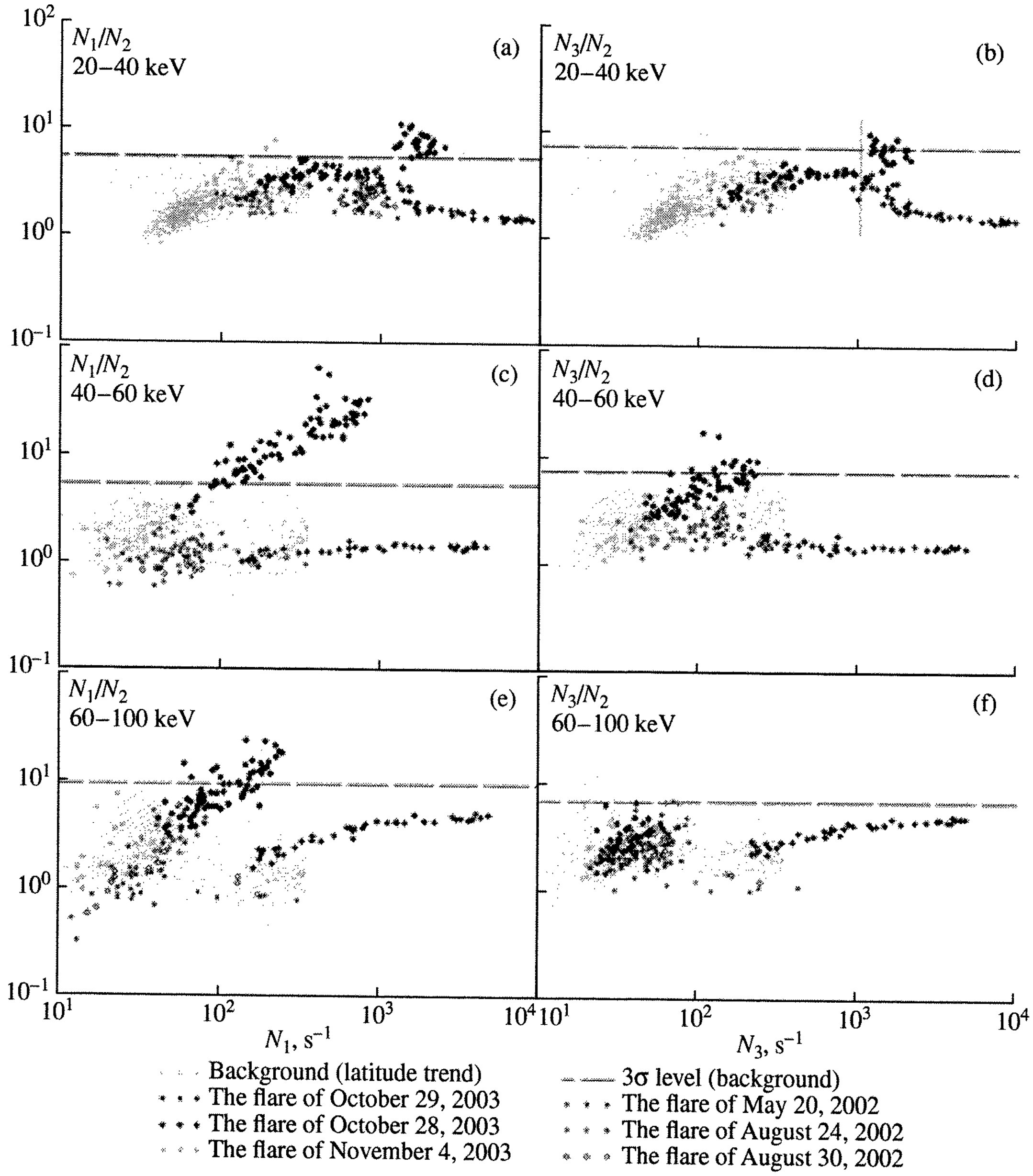

Fig. 5. The diagrams displaying the spread in the ratio of the polarization detector readings (N_1/N_2 and N_3/N_2) versus the total loading in channels 20–40 (a, b); 40–60 (c, d), and 60–100 keV (e, f).

mal phase of the flare of October 29, 2003), these ratios are almost in the same range. The existence of polarization explains such behavior immediately, since the polarization plane must be situated asymmetrically relative to detector nos. 1 and 3. It is clear that the influence of the systematic effects on the "anomalous" values of the N_1/N_2 ratio during the flare of October 29, 2003, cannot be eliminated completely. Specifically, one may suppose that the increased count rate in detector no. 1 can be induced by the spectral peculiarities of the recorded radiation and by the above-mentioned possible dependence of the detector efficiency on photon energy. However, by its spectral characteristics in the range 20–100 keV and the hardness of the radiation recorded, the flare of October 29, 2003, does not differ significantly from the other flares, including those associated with the same active region and observed by the SPR-N instrument on October 28 and November 4, 2003. That is why it seems improbable that such a high deviation of the N_1/N_2 ratio can be explained by the spectral dependence of the polarization detector efficiency. Apparently, the behavior of the outputs of the polarization detectors during this event can be considered as evidence for the presence of a polarized component in the hard X-rays.

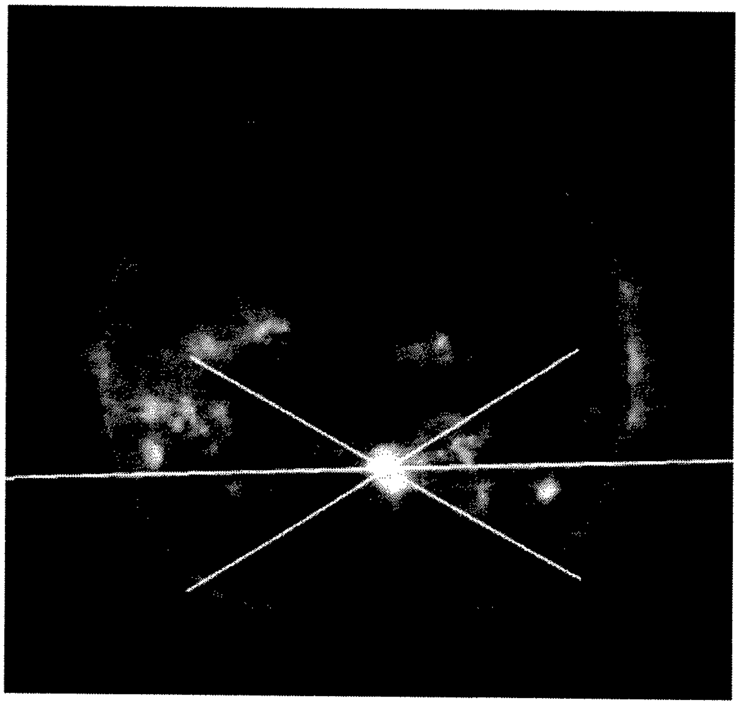

Fig. 6. The location of the polarization plane of the hard X-ray radiation on the solar disk from the SPR-N data. The soft X-ray image (175 Å) of the Sun was used; it was obtained during the flare of October 29, 2003, at 20:50:21 UT with the SPIRIT instrument onboard the *CORONAS-F* satellite.

To quantitatively estimate the polarization effect, the outputs of individual polarization detectors were normalized to the N_1/N_2 and N_3/N_2 ratios corresponding to measurements when the recorded radiation was surely not polarized, i.e., when the N_1/N_2 and N_3/N_2 values were within the 3σ limit. As an upper boundary of the normalizing coefficient, the value corresponding exactly to the 3σ level was chosen; it determines the lower boundary of the polarization degree error. The upper boundary of the polarization degree error was found from the detector outputs without normalization, because, as seen from Fig. 5, the lower limit of the spread in N_1/N_2 and N_3/N_2 corresponds to ~1.

The measurements of the part of polarized radiation are also presented in Fig. 4 (lower curve). As is seen from the plot, this part in the channel 40–60 keV is less than 85% and 75% during the first (at 20:44 UT) and second (at 20:51 UT) maximums in the hard radiation, respectively. For the flare of October 28, 2003, and for the initial stage of the event of November 4, 2003, the ratios of the initial outputs did not differ noticeably from the values measured at the equator, and the accuracy of determination of the normalizing coefficients allows one to choose them in such a way that the count rates of the detectors become equal. Consequently, only upper limits of the polarization degree can be given for these events: $P < 25\%$ and $< 40\%$ for the flares of October 28 and November 4, 2003, respectively. For the flares of October 29 and October 28, 2003, the accuracy in determining P is governed by the systematic error in the normalizing coefficients. For the flare of November 4, 2003, the error is significantly influenced by the statistical spread of the count rate in the polarization detector channels.

Figure 6 displays the position of the polarization plane of the hard X-rays on the solar disk during the flare of October 29, 2003, built from the SPR-N data. The image of the Sun shown in this figure corresponds to the moment of the flare and was obtained with the X-ray SPIRIT telescopes onboard the *CORONAS-F* satellite. As is seen from the figure, the polarization plane is approximately parallel to the solar equator. The measurement error is ±30°.

During two time intervals of the flare of August 25, 2001 (approximately from 16:27 UT to 16:30 UT and from 16:31 UT to 16:34 UT; see Fig. 2), the motor, providing the ±60° turn of the polarization detector unit, operated. During the first interval (at the initial stage of the flare), the increase in the SPR-N X-ray channels was accompanied by an increase in the electron channels of the SONG instrument also mounted onboard the *CORONAS-F* satellite. This indicates that the satellite was possibly passing the radiation-belt offsets at this time and makes it difficult to allow for the background in this interval. That is why only the second interval, corresponding to the flare-radiation decay (starting approximately from the intensity maximum), was chosen for determining the polarization degree.

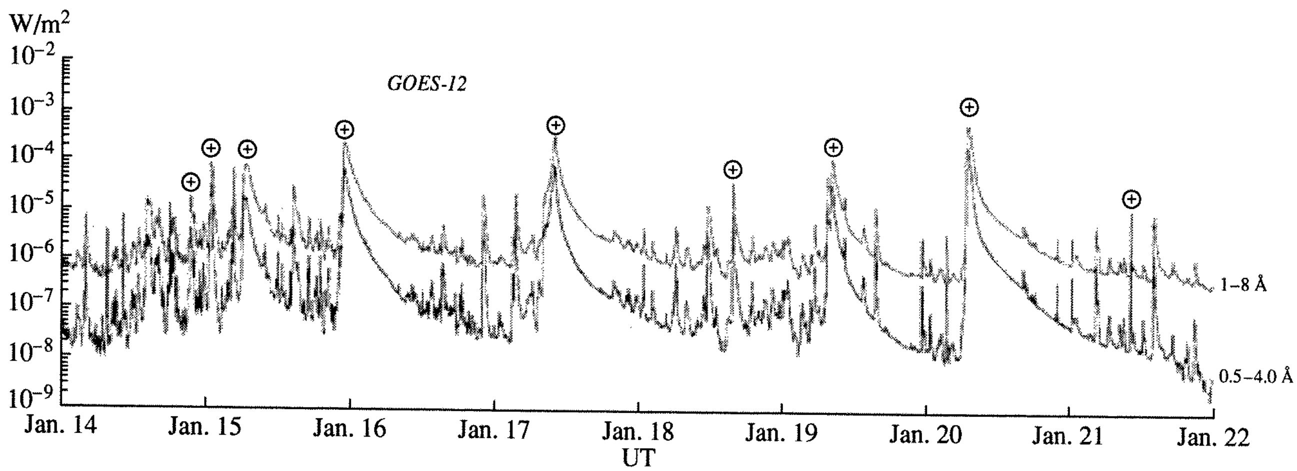

Fig. 7. The fluxes of soft X-ray radiation in 1–8 and 0.5–4 Å measured from the *GOES-12* satellite in January 2005 (the data from the site http://sec.noaa.gov). The "+" signs indicate the flares, for which the SPR-N patrol detector recorded the hard X-ray fluxes.

If the radiation is polarized, the differences in the count rates measured in two subsequent (odd and even) exposures by the same detector pair must be observed when the rotating platform is operating. In this case, the outputs must show an increase for one of the counter pairs and a decrease for the other one. However, the periodic change in the position of the assemblage of detectors does not remove the effects connected with the position of the detectors relative to the satellite mass (due to this, the background fluxes can differ for different detectors), although this smoothes the spread in readings caused by different detector efficiencies in recording the radiation not scattered in the Be-polarimeter.

To find the part of polarized radiation in the flare of August 25, 2001, we used the differences in the detector outputs in odd and even exposures, which were less than 10% in the 40- to 60- and 60- to 100-keV channels. The calculations show that the part of polarized radiation for the flare of August 25, 2001, was less than 8.5% (at a 3σ level) for the time period from 16:31 to 16:34 UT.

SOLAR FLARES IN JANUARY 2005 AS OBSERVED WITH THE SPR-N INSTRUMENT

A significant level of the solar-flare activity was observed in January 2005. Figure 7 presents the data on the soft X-rays (at wavelengths of 1–8 and 0.5–4 Å) collected by the *GOES-12* satellite for the period from January 14 to January 22, 2005 (the information was taken from the site http://sec.noaa.gov). All the strongest events observed in this period had the same source, region 10720, and, unlike the active period of October–November 2003, no other active regions were practically observed. During the period from January 14 to January 22, 2005, the region crossed the whole solar disk; it was at 61° W when the strongest of the all observed flares occurred (on January 20; X7.1 class). A list of nine flares for which the SPR-N patrol detector detected the hard X-rays with energies of 15–40 and 40–100 keV is given in the table. These flares are marked with "+" in Fig. 7.

The parameters of the solar flares occurring in mid-January 2005, for which the SPR-N instrument detected hard X-rays (the data is from the site http://sec.noaa.gov)

Date	Flare time, UT			*GOES* class	Ratio (0.5–4 Å)/(1–8 Å) in maximum	Flare coordinates	SPR-N (polar)
	Onset	Maximum	End				
14.01.2005	21:08	21:26	21:39	M1.9	2.3*E*–02	N14E10	No
15.01.2005	00:22	00:43	01:02	X1.2	1.2*E*–01	N14E08	No
15.01.2005	05:54	06:38	07:17	M8.6	2.9*E*–01	N16E04	No
15.01.2005	22:25	23:02	23:31	X2.6	6.3*E*–01	N15W05	Yes
16.01.2005	21:55	22:03	22:22	M2.4	2.4*E*–02	N15W19	No
17.01.2005	06:59	09:52	10:07	X3.8	8.4*E*–01	N15W25	Yes
19.01.2005	08:03	08:22	08:40	X1.3	2.2*E*–01	N15W51	No
20.01.2005	06:36	07:01	07:26	X7.1	1.3*E*+00	N16W61	Yes
21.01.2005	10:10	10:16	10:19	M1.7	4.5*E*–03	N19W81	No

An increase in the polarization detector channels was observed only for three of these flares (see table). For the flare of January 15, 2005 (~23:02 UT), the response in the polarization channels was insignificant as compared to the background (the satellite was within the polar cap). During most the flare of January 17, 2005, the Earth screened the Sun, and the increase in the polarization channels was observed only at the very end of the flare, when the radiation could not have been polarized. In this connection, for this period, the polarization degree was only estimated for the flare of January 20, 2005. During the flare, the polarized radiation did not exceed 17%.

CONCLUSIONS

In the near future, the catalog of the solar flares of class M1 and higher will be presented at the site http://www.coronas.ru. For the flares detected in hard X-rays by the SPR-N instrument, we will display the time dependence of X-ray intensity. For the flares which were not detected by SPR-N, we will either give plots evidencing the absence of radiation or explain the causes why the SPR-N instrument did not observe these flares. The catalog will also contain the radiation polarization levels or the causes why we failed to estimate the polarization degree.

Now, we are also working on estimating the relative contribution of the thermal and nonthermal inputs into flare hard X-rays.

ACKNOWLEDGMENTS

The work was supported by the Russian Foundation for Basic Research (project no. 04-07-90337).

REFERENCES

Bogomolov, A.V., Denisov, Yu.I., Kuznetsov, S.N., et al., Hard X-ray Radiation from Solar Flares in the Second Half of 2001: Preliminary Results of the SPR-N Experiment Onboard the *CORONAS-F* Satellite, *Astron. Vestn.*, 2003a, vol. 37, no. 3, pp. 127–136 [*Sol. Syst. Res.* (Engl. Transl.), 2003a, vol. 37, no. 3, pp. 112–120].

Bogomolov, A.V., Denisov, Yu.I., Logachev, Yu.I., et al., Time, Spectral, and Polarization Characteristics of Hard X-Ray Radiation of Solar Flares Observed during the SPR-N Experiment aboard the *CORONAS-F* Orbital Observatory, *Izv. Ross. Akad. Nauk, Ser. Fiz.*, 2003b, vol. 67, no. 10, pp. 1422–1426.

Dennis, B.R., Solar Hard X-Ray Bursts, *Sol. Phys.*, 1985, vol. 100, p. 465.

Guzman, A.B., Kudryavtsev, I.V., and Charikov, Yu.E., The Evolution of Electrons Accelerated in Solar and Stellar Flares and the Pulsed Structure of Hard X-ray Radiation, *Astron. Zh.*, 1996, vol. 73, no. 2, pp. 273–279 [*Astron. Rep.* (Engl. Transl.), 1996, vol. 40, no. 2, pp. 246–251].

Kahler, S.W., Cliver, E.W., Kane, S.R., et al., Filament Eruptions and the Impulsive Phase of Solar Flares, *Astrophys. J.*, 1988, vol. 328, p. 824.

Kahler, S.W., Daibog, E.I., Kurt, V.G., and Stolpovskii, V.G., A Comparison of Nonrelativistic Electron Escape Efficiencies for Solar Flares with and Without Coronal Mass Ejections, *Astrophys. J.*, 1994, vol. 422, p. 394.

Rausariya, R.R. and Tindo, I.P., Measurements of Polarization of Hard X-Ray Radiation of the Sun: the *CORONAS-F* Project, *Kompleksnoe issledovanie Solntsa i solnechno-zemnykh svyazei (Tr. III Mezhdunarod. soveshch. "KORONAS-I" (Kaluga, 1988))* (Complex Study of the Sun and Solar-Terrestrial Relations (Proc. of the III Int. Conf. "*CORONAS-I*" (Kaluga, 1988))), Leningrad, 1989, pp. 72–79.

Skrynnikov, Yu.I., Polarization of Hard X-Ray Radiation of a Solar Flare, *Tr. Vtorogo ezhegodnogo seminara "Problemy fiziki solnechnykh vspyshek" (Riga, 1983)* (Proc. of the Second Annual Seminar "Problems of Solar-Flare Physics" (Riga, 1983)), Moscow, 1985, pp. 162–167.

Stepanov, V.E., Ed., *Solnechnye vspyshki* (Solar Flares), Moscow: Nauka, 1982.

Tindo, I.P., Ivanov, V.D., Mandel'shtamm, S.L., et al., Detection of Polarization of X-Ray Radiation in Solar Flares, *Kosm. Issled.*, 1971, vol. 9, no. 1, p. 116.

Tindo, I., Ivanov, V., Mandelstam, S., et al., New Measurements of Polarization of X-Ray Solar Flares, *Sol. Phys.*, 1972, vol. 24, p. 429.

Veselovsky, I.S., Panasyuk, M.I., Avdyushin, S.I., et al., Solar and Heliospheric Phenomena in October–November 2003: Causes and Effects, *Kosm. Issled.*, 2004, vol. 42, no. 5, pp. 453–508 [*Cosmic. Res.* (Engl. Transl.), 2004, vol. 42, no. 5, pp. 435–488].

Zhitnik, I.A., Tindo, I.P., and Urnov, A.M., Investigation of Solar X-Ray Radiation in the Lebedev Institute of Physics, Russian Academy of Science, *Tr. Fiz. Inst. im. P.N. Lebedeva, Ross. Akad. Nauk*, 1989, vol. 195, pp. 3–18.