First Two Months Operation of Hard X-ray Polarimeter "PENGUIN-M" On-board Satellite "CORONAS-PHOTON"

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***Abstract*. The operation of the "PENGUIN-M" device on board the "CORONAS-PHOTON" spacecraft during first months in orbit is described. Characteristics of the device are given as well as general description of software for experimental data processing and analysis. The progress of in-flight adjustment of the "PENGUIN-MD" detector unit in actual background conditions is described. Observation results are reported for soft X-ray solar flare emission and hard X-rays from cosmic gamma-ray bursts. The registered events were used for estimating the sensitivity of the device.**

***Keywords*: CORONAS-PHOTON, solar flares, polarimeter**

I. Introduction

Hard X-ray polarimeter "PENGUIN-M" [1] was launched on January 30, 2009 onboard of Russian scientific satellite "CORONAS-PHOTON" [2], [3] and allows to measure: degree of hard X-ray linear polarization in the range of energies 20-150 keV, solar flares radiation spectra at energy range of 18-450 keV (96 energy channels), soft X-ray spectra at energy range of 2-20 keV (12 channels), including weak (thermal) flares and preflare radiation level.

II. Short device description

Hard X-ray polarimeter "PENGUIN-M" consists of two blocks: the detector block "PENGUIN-MD" (PMD), mounted on devices platform of satellite and the electronic block "PENGUIN-ME" (PME) in hermetic vessel of satellite. The PMD block is developed and produced by Ioffe Physical-Technical Institute, RAS, the PME block - by Moscow Engineering Physics Institute (MEPhl). Assembled PMD is shown on Fig. 1.

The PMD block is based on organic and inorganic scintillators and proportional counters. The connection of the PMD block with the spacecraft on-board systems and with the data acquisition and registration of scientific information system (SSRNI) is carried out through the PME block. Five basic elements constitute the structure of the block detection part:

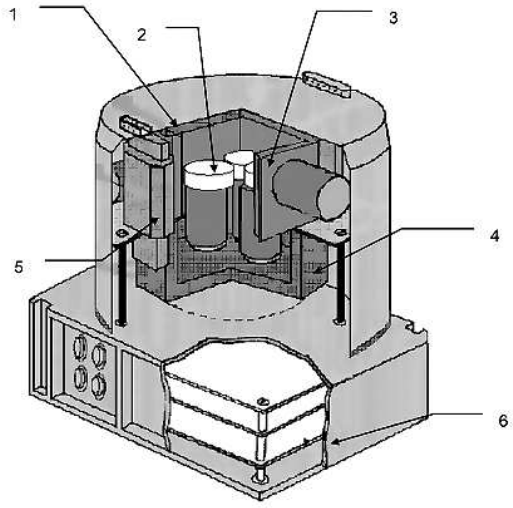


Fig. 1: The design of the "PENGUIN-M" detector block. 1: top shield detector (polystyrene+PMT); 2: detector-scatterer SD (paraterphenyl+PEM); 3: phoswich-detectors PD (NaI+polystyrene); 4: bottom shield detector (polystyrene); 5: soft x-ray detectors (proportional counters); 6: digital electronics plates

1) Detector-scatterer of hard X-rays which is in fact the assembly in the form of a disk from four sectors of paraterphenyl (PTF) crystals located below photomultiplier and electronics.
2) Six detectors of scattered and direct X-ray and gamma-radiation are assembled in a regular hexahedron installed around the scatterer. Each detector contains crystal NaI(TI), protection from the background noise of charged particles by the phoswich scheme.
3) The upper, side and lower anticoincidence screen detectors. All anticoincidence screen detectors with PMT are used for the detectors protection from charged particles background. The effectiveness of the background registration by all anticoincidence screens is not worse than 0.999.
4) The degree of linear polarization and polarization plane positional angle of hard X-rays are mea-

sured by asymmetry of Compton scattering in case of polarization of an incident flux. Paraterphenyl detectors serve for registration of Compton recoil electrons and Nal(TI) detectors serve for registration of scattered radiation. "PENGUIN-M" also registers radiation incident on the upper surfaces of the scattered radiation detectors in the energy range of 18-450 keV in the absence of coincidences with impulses from the detector-scatterer. The instrument also registers radiation incident on the detector-scatterer in the energy range of 15-40 keV in the absence of coincidences with impulses from scattered radiation detectors.

5) Two assemblies of soft X-ray detectors include proportional counters, preamplifiers, a high-voltage power supply and a block of analogue-digital processing of signals. Soft X-Ray radiation in the energy range of 2-20 keV is registered by two proportional counters with beryllium entrance windows and pure xenon filling The width of the channel is about 0.2 keV at the lower energy threshold, it increases with radiation energy up to $\sim$2 keV. The proportional counter comprises 4 sections, disposed one under another in a common gas volume (xenon at 1 atm pressure). The upper section is intended for registration of radiation in the energy range 2-20 keV from weak flares (the maximum effective area is $\sim 0.32\ cm^2$ at 16 keV, 13 energy channels). The second section, due to X-ray absorption in the gas of the upper section, can register, with no overload, radiation of high-power flares (lower energy threshold is $\sim$8 keV, the maximum effective area $\sim 0.16\ cm^2$ at 18 keV, 13 energy channels). The third section is practically insensitive to X-rays and is used for background control. The fourth section is provided by Fe^{55} (5.9 keV) source for in-flight calibration.

The polarimeter is provided by systems for energy scale stabilization (using a weak radioactive source) and those of monitoring of device symmetry. These systems allow to maintain stability at the level of 1%. The instrument is working in two modes: "PATROL" and "FLARE" with different temporal resolutions. The data from "PENGUIN-M" has some types:

- Type A: technical data and spectral data from both proportional counters;
- Type B: full spectral and coincidence information from all detectors and polarization matrices;
- Type C: integral fluxes from both proportional counters, anticoincidence detectors and from opposite pairs of detectors of scattered and direct X-ray and gamma-radiation.

Time resolution for Data Type A equals 10 s, and for Data Type B time resolution depends from the operational mode: in "PATROL" mode 120 s, in "FLARE" mode 10 s. Data Type A and Data Type B are synchronized and time resolution can be changed by telecommand. All Types of Data included special time data with accuracy about 1 ms relatively UT.

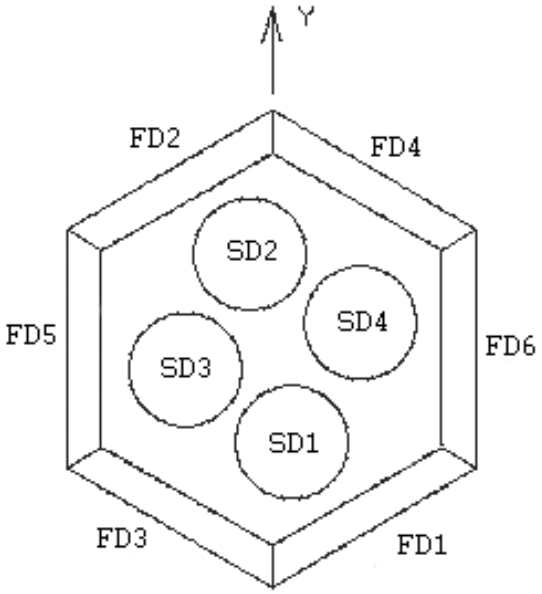


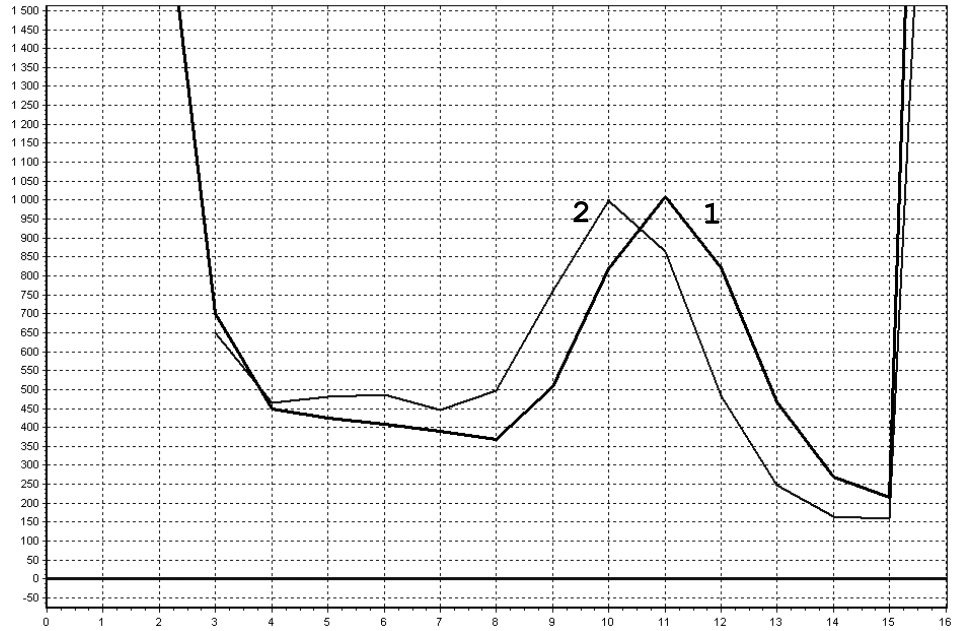
Fig. 2: The positionning of scatterer detectors (SD) and phoswich detectors (FD)

III. Preflight calibrations and modelling

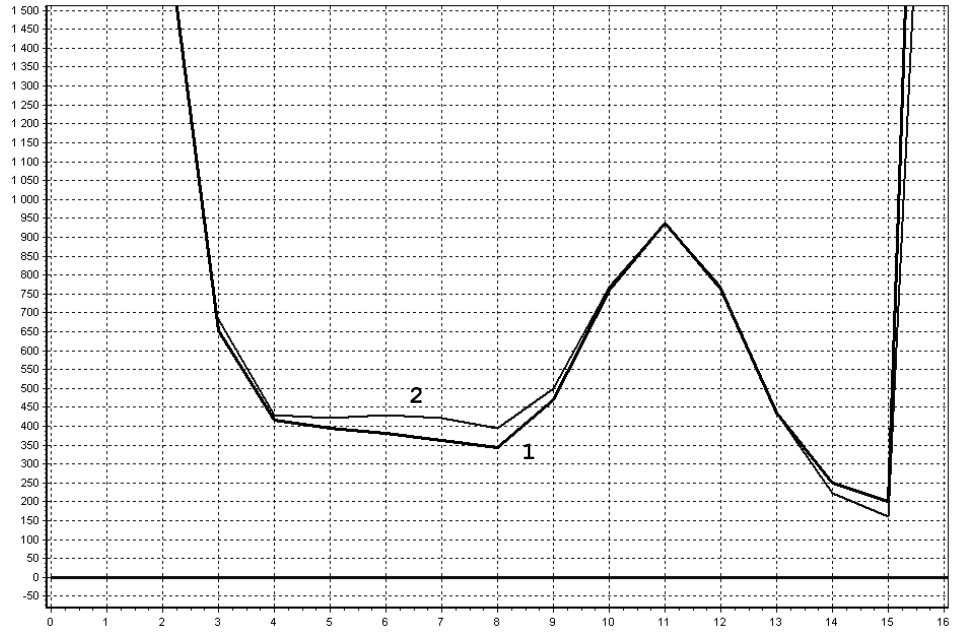
The structure of the "PENGUIN-M" detector unit is rather complicated and not completely symmetric (see Fig. 2). Therefore a mathematical modelling of the device was necessary. Modelling was performed by means of GEANT4 software. In ground calibration we used radioactive sources: Cd^{109} (22-25 keV, 88 keV), Am^{241} (59 keV), Ba^{133} (31-35 keV, 81 keV). Before the calibration procedure, response of detectors was checked using the embedded Ba^{133} source. Geometrical factors for each pair of detectors (scatterer+phoswich) was measured for several X-ray lines for non-polarized and for almost completely polarized radiation. Non-polarized beam was obtained from a radioactive source placed at the optical axis of the device at a distance of 2.5 m. The total pulse count in double coincidence channels exceeded 10^7. A source of polarized radiation was obtained with use of Compton scattering at the angle of 90°.

IV. Flight calibrations

An analysis showed that peak location in pulse height spectra of the embedded Ba^{133} source remains stable for all period from February 19, 2009 to present time. As a result of ground calibration, the peak positions were set equal in scatterer detectors with accuracy nearby 1% and in phoswich detectors with accuracy of about 2.5%. After launch we observed some displacement of peaks, but not exceeding 10%. This discrepancy is now almost completely removed



(a) before adjustment



(b) after adjustment

Fig. 3: Calibration source spectrum (Ba^{133}, 30 keV) of one of scatterer detectors (1-ground, 2-orbit calibration)

by adjusting high voltage by radio commands. The progress of adjustment is illustrated by figures. The estimates by various methods show that the difference of in-flight and ground spectra was achieved with accuracy of 1-2%. Fig. 3a, 3b show examples of energy spectrum before and after adjustment. In general, the "PENGUIN-M" device has registered 12 solar flares till May 12, 2009 in soft X-rays. A part of them is listed in the GOES catalogue, and others are not, as these last have a X-ray class below B1.0. Some flares given in the GOES catalogue were not detected because the spacecraft was at night side, or in radiation belts, or in South Atlantic Anomaly area. We also registered some cosmic gamma-rays bursts, some of them was registered by other devices onboard "CORONAS-PHOTON" or on other missions. Fig. 4 shows example of soft X-ray data from solar flares. On March 26, 2009 the large window section of the proportional counter registered two events, one with a maximum around 01:07 UT, another with a maximum around 01:43 UT. The small window section did not feel radiation from these flares. It is due to its smaller effective area to high sensitivity

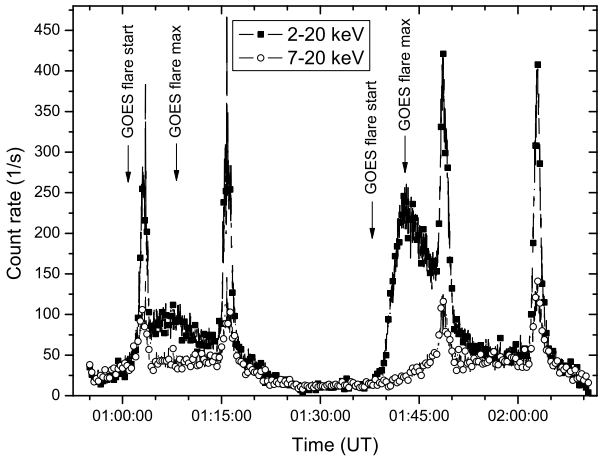


Fig. 4: Soft X-ray flare on March 26, 2009 as registered by soft X-ray detector detectors

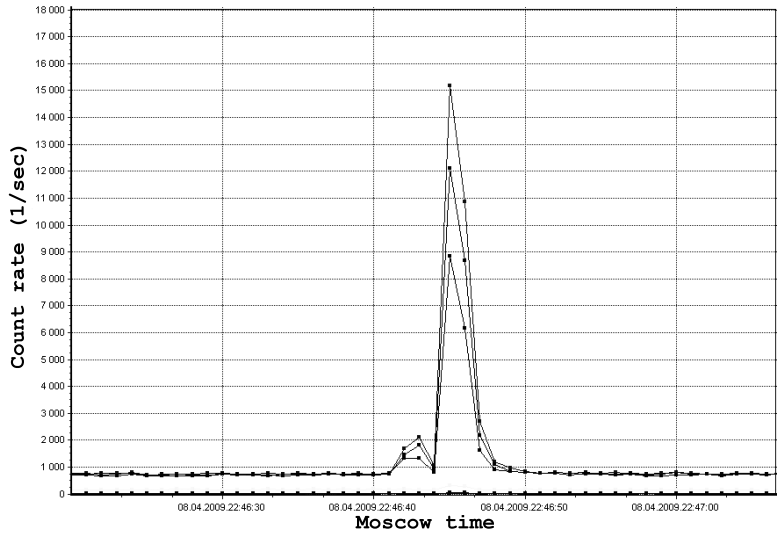


Fig. 5: Gamma ray burst on April 08, 2009. Count rates in three pairs of phoswich detectors

threshold, nearby 8 keV. As can be seen from the spectra, the counts in the channels, corresponding to energy above 8 keV, are practically absent. The second, more intense flare on March 26, 2009 is reported in GOES X-ray solar flares data (Event 390, beginning 01:38 UT, maximum 01:43 UT, end 01:49 UT, class B1.8). The first flare registered by us is missing in GOES summary list, for there are only flares of class B1.0 and higher. The result indicates that sensitivity of the "PENGUIN-M" device to soft X-rays flares with the 1 s time resolution is not worse than A1.0, and with the time resolution of 10 s will be much better than level A1.0. On Fig. 5 is shown the example of cosmic gamma-rays burst time profile.

V. SUMMARY

Now the "PENGUIN-M" device is in fully operational mode. First results show, that our experiment is ready for registration of solar flares.

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