Solar mission "Coronas-Photon": in-orbit status and first results

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***Abstract*. This paper describes the main characteristics of the Russian "Coronas-Photon" mission launched on 30 January 2009. "Coronas-Photon" is the third satellite of the Russian Coronas program on solar activity observation. All scientific onboard instruments are working as expected. Several examples of the observation are presented in the article: soft solar flares, images of solar disc in EUV and UV, light-curves of soft X-ray radiation and cosmic gamma-bursts.**

***Keywords*: Coronas-Photon satellite**

I. INTRODUCTION

CORONAS (**C**omplex **OR**bital **O**bservations **N**ear-Earth of **A**ctivity of the **S**un) – Russian program for study of the Sun and solar-terrestrial connections physics by series of spacecrafts, which provides launching of three solar-oriented satellites onto the near-Earth orbit. "Coronas-Photon" is the third satellite in this series. Two previous missions are "Coronas-F" (launched on July 31, 2001) and "Coronas-I" (launched on March 2, 1994). This program is sponsored by Russian space agency Russian academy of science.

Satellite "Coronas-Photon" is Sun-pointing orientation spacecraft. It was launched from cosmodrome "Plesetsk" (Russia) into a low-Earth low-eccentricity, high-inclination orbit (altitude about 550 km, inclination 82.5 deg). Principal scientific organization and mission operator is Moscow Engineering Physics Institute (MEPHI). Spacecraft was designed and fabricated by "Research Institute for Electromechanics" (Moscow region).

The main goal of the "Coronas-Photon" is the investigation of energy accumulation and its transformation into energy of accelerated particles processes during solar flares; the study of the acceleration mechanisms, propagation and interaction of fast particles in the solar atmosphere; the study of the solar activity correlation with physical-chemical processes in the Earth upper atmosphere.

II. SCIENTIFIC PAYLOAD

Scientific payload of the mission for solar radiation observation would register solar hard electromagnetic radiation in the wide energy range from UV up to high energy gamma-radiation. The instrument assembly consists of three types of instruments:

- Eight monitors ("**Natalya-2M**", "**Konus-RF**", "**Penguin-M**", "**RT-2**", "**BRM**", "**Phoka**", "**Sphin-X**", "**Sokol**") for registration of full Sun solar electromagnetic radiation (from UV to high energy gamma-rays). One of them is able to registered the solar neutrons $>$ 20MeV;

- One telescope-spectrometer "**TESIS**" for imaging solar spectroscopy in EUV and soft X-rays with angular resolution up to 1";
- Two instruments ("**Electron-M**" and "**STEP-F**") for charge particle registration (protons, electrons, α-particles);
- One magnetometer "**SM-8M**".

Observational capabilities of the instruments are given in Table 1.

High energy spectrometer NATALYA-2M registration block includes two spectrometers of eight scintillation modules with CsI(Tl) crystals each. All scintillation modules are identical, they are CsI(Tl) crystal based blocks 4.5x8x38cm in size. Modules form two layers (4 crystals in each); the nearby layers are rotated relative to each other by 90 deg. The upper spectrometer is surrounded by the polystyrene anticoincidence protection which consists of the 1.5 cm thick scintillation dome and plane detector. Effective area of the instrument scales from 920cm^2 to 750cm^2 in the energy range from 0.2 to 2000 MeV. The detailed information on this instrument is presented in the (ID 1533) poster at this conference.

Low energy gamma-ray telescope RT-2 includes three detector blocks RT-2/S, RT-2/G, RT-2/CZT. Composite scintillation detectors (phoswich 3mm NaI(Tl)/25mm CsI(Na) with diameter of 11.6 cm) are used in RT-2/S and RT-2/G blocks. Scintillation detectors work simultaneously in two energy ranges: 15 - 150 keV (RT-2/G) and 20 - 150 keV (RT-2/G)(phoswitch mode) and 0.27 - 1 MeV (spectrometric mode for full signal from both scintillators). RT-2/S and RT-2/G blocks are covered by passive shielding and collimators with 4x4 and 6x6 degrees angles of sight respectively. Detectors are calibrated in orbit using low energy radioactive Co-57 source.

RT-2/CZT block has two hard X-ray detectors. One of them is based on a semiconductor CZT. Effective CZT detector area is 48 cm^2, achieved by using three 40x40mm modules. Each module is 2.5x2.5mm element matrix (5 mm thick). 40cm above two CZT modules there are random coded aperture mask (CAM). Each element is 2.5x2.5mm. Measured angular resolution for CZT composition is 30 angular minutes. Resolution may be increased till 2 angular minutes for powerful flares. Another detector of RT-2/CZT block is made of GdOS scintillator 25x50mm and 3mm thick, situated in optical contact with CMOS matrix and effective pixel size of 48x48mkm. For modulation photons flux till 100keV there are two collimators 40cm above one CZT and GdOS/CMOS detectors in the form of two 1 mm tungsten Frenel plate each. According to laboratory testing for the most powerful flares with simple structure the angular resolution may be up to 10 angular seconds. The detailed description of the instrument and first observational results are presented in the poster (1525) at the conference.

Hard X-ray polarimeter-spectrometer PENGUIN-M. Five basic elements constitute the structure of the detection part. 1) Detector-scatterer of hard X-rays which is p-terphenyl (PTF) crystals assembly in the form of a four sectors disk. 2) Six NaI(Tl) detectors of scattered and direct X-ray and gamma-radiation assembled in a regular hexahedron are installed around the scatterer. 3) The upper and bottom anticoincidence screen plastic scintillator detectors. 4) Two assemblies of soft X-ray detectors include proportional counters for 2-20keV photon registration. Instrument has capability to measure the linear polarization of solar hard X-rays flux using azimuth asymmetry of Compton scattering. The detailed description of the instrument and first observational results are presented in the poster (1534) at the conference.

X-ray and gamma-ray spectrometer KONUS-RF instrument uses two detector blocks based on scintillatiors NaI(Tl) 127 mm in diameter and 76.2mm in heigh. One block is oriented to the Sun, another in the anti-Sun direction. Continuous measurements of radiation intensity are made in the background mode in the energy range of 10keV - 12MeV. Time resolution is 1 - 2 seconds. Measurements of multi-channel energy spectra are carried out in the range of 200keV - 8MeV with accumulation time from one to several minutes. Time resolution automatically adapts to a current level of counting rates depending on the observation task and covered energy range. It may vary from 2 ms up to several minutes.

Fast X-ray monitor BRM is based on a fast scintillation detector $YAlO_3$(Ce). It has the following parameters: de-excitation time is 28 ns; density is 5.35 g/cm^3; maximum wavelength in emitted spectrum is 347 nm. The crystal has a cylindrical shape with dimensions of 10 mm in height and 70 mm in diameter. BRM registers radiation in the energy range of 20 - 600keV, divided into six differential and two integral interval.

EUV/XUV photometer PHOKA has seven channels of observation (See Table 2). Each registration channel includes a silicon photodiode AXUV in assembly with a collimator and an appropriate spectral filter, a preamplifier and a voltage-to-frequency converter. Channels #4, #5 #6, #7 have photodiodes with directly deposited filters. Channels #2 and #3 have outer interference filters. Channel #1 (visual) has no filter. PHOKA detectors were absolutely calibrated before flight with accuracy better than 10%. By commands channels may be covered by impenetrable or fused silica filters to make background measurement. Each equivalent pair of detectors has one primary detector and one redundant. Most of the time redundant channels are closed by absorbing shell of the detector what helps to lessen the degradation of these channels.

During occultation satellite position the solar disk is observed through the Earth atmosphere, it is possible to obtain temperature and density distributions and to specify theoretical and empirical models of thermosphere and ionosphere.

Fast Solar Photometer in X-rays SphinX detects soft (0.5 keV - 15 keV) X-ray photons from entire

Instrument	Parameters, registered radiation	Developing organization
Electromagnetic radiation and neutron monitors		
High energy spectrometer NATALYA-2M	- Gamma-ray spectroscopy 0.2 - 2000 MeV - solar neutrons 20 - 300 MeV	MEPhI, Moscow, Russia
Low energy gamma-ray telescope RT-2	- Hard X-ray spectroscopy 15 - 150 keV in phoswich mode - spectrometric mode 0.10 - 1 MeV - Hard X-ray solar flares image	TIFR, Mumbai ICSP, Kolkata, India
Hard X-ray polarimeter-spectrometer PENGUIN-M	- Hard X-ray polarization 20 - 150 keV - soft X-ray monitoring 2 - 20 keV - X-ray & gamma-ray spectroscopy 0.015 - 5 MeV	MEPhI, Moscow, Russia; Ioffe PhTI, St-Petersburg Russia
X-ray and gamma-ray spectrometer KONUS-RF	Solar flares and gamma-ray bursts hard X-ray & gamma-ray spectroscopy in the energy range of 10 keV - 12 MeV with high time resolution	Ioffe PhTI, St-Petersburg, Russia
X-rays		
Fast X-ray monitor BRM	Hard X-ray monitoring 20 - 600 keV in six channels with time resolution 2 - 3 ms	MEPhI, Moscow, Russia
Fast Solar Photometer in X-rays SphinX	Measurements with high time resolution (0.01 s) of the solar spectra of quiet and active corona in the range 0.5 - 15 KeV	SRC, Wroclaw, Poland
EUV/XUV photometer PHOKA	- Full disk EUV/XUV radiation in three pair spectral bands 0,5 - 11 nm, 27 - 37 nm, 121,6 nm - occultation measurements of EUV/XUV absorption in Earth atmosphere 150 - 500 km	MEPhI, Moscow, Russia
Solar telescope/imaging spectrometer TESIS	Solar images registration in narrow spectral regions and monochromatic radiation lines of transition zone and corona: - telescope 130 - 136 $\AA$, - telescope-coronograph 290 - 320 $\AA$, corona (0,2 - 4) Ra - spectroheliometer (8,418 - 8,423) $\AA$, 285 - 335 $\AA$ - photometer-spectra heliometers 1 - 12 $\AA$, resolution 0,05 $\AA$ Angle of view up to 2 angular degrees.	Lebedev FIAN, Moscow Russia
Helioseismology		
Multichannel solar photometer SOKOL	Continuous observations of solar optical radiation variations in seven spectral channels at wavelength range of 280 - 1500 nm, view range - 2°	IZMIRAN, Troitsk, Russia
Cosmic rays		
Charged particle analyzer ELECTRON-M-PESCA	Flux and energy spectra registration: protons 4 - 80 MeV electrons 0.2 - 4 MeV nuclei (, N, O) 6 - 15 MeV/nucleon	Skobeltsyn INPh, Moscow, Russia
Satellite telescope of electrons and protons STEP-F	Flux and energy spectra registration: protons 9.8 - 61.0 MeV electrons 0.2 - 15 MeV α- particles 15,9 - 246.0 MeV with accuracy of particle direction (8 - 10)°	Karazin KNU, Kharkov, Ukraine
Scientific supply systems		
Magnetometer SM-8M	Measurements of three components of constant magnetic field on satellite orbit in the range of -55 μT +55 μT	Geologorazvedka, St-Petersburg, Russia MEPhI, Moscow, Russia

TABLE I: Observational capabilities of the instruments

Channel	Bandpass, nm
#1(Optic, technological)	150- 1100
#3(Ly-a, primary)	116- 125
#6(Cr/Al, primary)	(0,5- 7)&(27- 37)
#7(Ti/Pd, primary)	0,5- 11
#2(Ly-a, redundant)	116- 125
#5(Cr/Al, redundant)	(0,5- 7)&(27- 37)
#4(Ti/Pd, redundant)	0,5- 11

TABLE II: Spectral bands of PHOKA instrument

solar corona (5 deg FOV) in 256 energy channels (100 times/sec) (rates: 102 - 103 /bin/sec)/ Energy resolution (150-190 eV). Direct full Sun fluxes through three calibrated apertures of: 19.96, 0.397 and 0.0785 mm^2 with three identical Si 500 μm PIN detectors: overall dynamic range seven orders of flare magnitude from A1 to X40.

For GOES activity levels below B (rates: 10^3 - 10^5 /sec) the time and energy stamping technique (1 μs temporal accuracy) may be used. For detector calibration the new measurement's concept of fluorescence in sharp narrow "spectral difference" band is developed and used.

The digital electronics, power supply, command and telemetry interface are integrated with instrument TESIS.

Solar telescope/imaging spectrometer TESIS is a complex of space telescopes developed for research of structure and dynamics of solar corona with spatial resolution of 2 angular seconds and temporal resolution at least 30 seconds. In fact it includes 4 scientific instruments. The main parameters of them are presented in Table 3. Each telescope is an autonomous instrument and may operate as independently as in complex with others.

Telescope	Instrument description	Wavelength range	Field of view	Angular resolution
MISH	Bregg Specrtoheliometer with spherical crystalline mirror	Hydrogen-like ion line duplet MgXII 8,418A and 8,423A	1,15° (full solar disk)	2”/pixel
EUSH	EUV Spectroheliometer with diffraction grating off-normal incidence and multi-layered parabolic focusing mirror	280-330A	1,24° (full solar disk compressed along dispersion axis)	4,4” (perpendicular dispersion axis) 1,5’ (along dispersion axis)
FET (telescope 1)	Herschel Telescope with multi-layered parabolic focusing mirror	130-136A	1,0° (full solar disc)	1,7”/pixel
FET (telescope 2)	Herschel Telescope with multi-layered parabolic focusing mirror	290-320A	1,0° (full solar disc)	1,7”/pixel
SEC	Ritchey - Chretien Coronagraph	290-320A	2,5° (inner and outer corona at distance from 0,7 till 4 Sun radiuses)	5”/pixel

TABLE III: TESIS main parameters

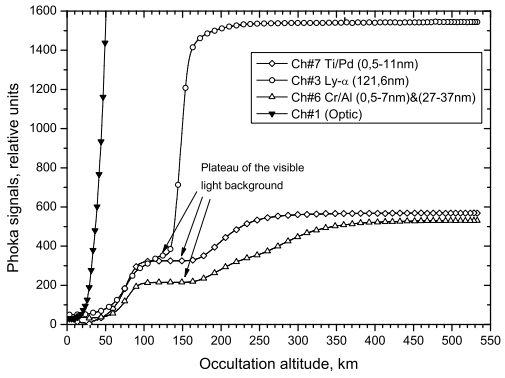

Fig. 1: PHOKA occultation lightcurve

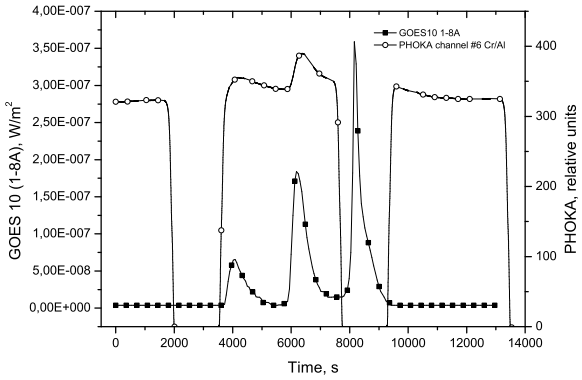

Fig. 2: Solar flares 09.03.26 lightcurves by PHOKA and GOES

Multichannel solar photometer SOKOL measures solar activity variations in seven optical ranges from near ultraviolet till infrared to determine global solar variations characteristics.

III. INSTRUMENTS STATUS AND FIRST OBSERVATIONAL RESULTS

All instruments are working in the observational mode. Scientific information is downloaded to Moscow station four times per days. All primary information is transmitted to MEPhI for primary processing and distribution between users.

To present time due to solar long quite duration only a few soft flares with photon energy less 10keV have been registered by PHOKA, SphinX and Penguin-M. Dynamic of active regions in EUV were observed many times by TESIS instrument including several observation in coordination with HINODE instruments. Konus and other instruments have observed about a dozen cosmic gamma burst including very intensive one GRB090408. For the last event the energy spectrum is measured up to 10 MeV. Some observed data are illustrated by Fig.1 - Fig.3.

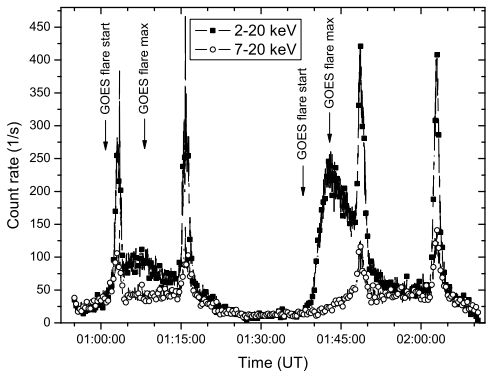

Fig. 3: Solar flares 09.03.26 lightcurve by PENGUIN-M

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