Chapter 3

Information about Scientific Projects of the Federal Space Program of the Russian Federation with are at the Development Stage

CONTENT

3.1. NUCLEON-2 space experiment

(Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University)

The study of the component of cosmic rays represented by the nuclei of superheavy elements (heavier than iron, up to transurans inclusive) is of particular interest for astrophysics, especially for the problem of the origin of chemical elements. The emergence of super-heavy elements is associated with processes in the supernova remnants and with such exotic processes as the fusion of neutron stars, which are now observed in gravitational astronomy. Of particular interest here is the study of the isotopic composition of superheavy nuclei, which at present remains an absolute terra incognita. At the stage of preparation is the space experiment NUCLEON-2, the main purpose of which is exactly the study of the isotopic composition of the superheavy component of cosmic rays. The beginning of the experiment is planned for 2020-2022. The spectrometer is a set of "towers", each of which is a stack of several dozen flat silicon detectors. The isotopic composition is determined by the features of the deceleration of the nuclei in these stacks. Fig.73. shows the expected appearance of the spectrometer, placed as an additional payload on the Resours-P spacecraft, and an example of the decomposition of the nuclear flux into isotopes (for the In nuclei, computer simulation).

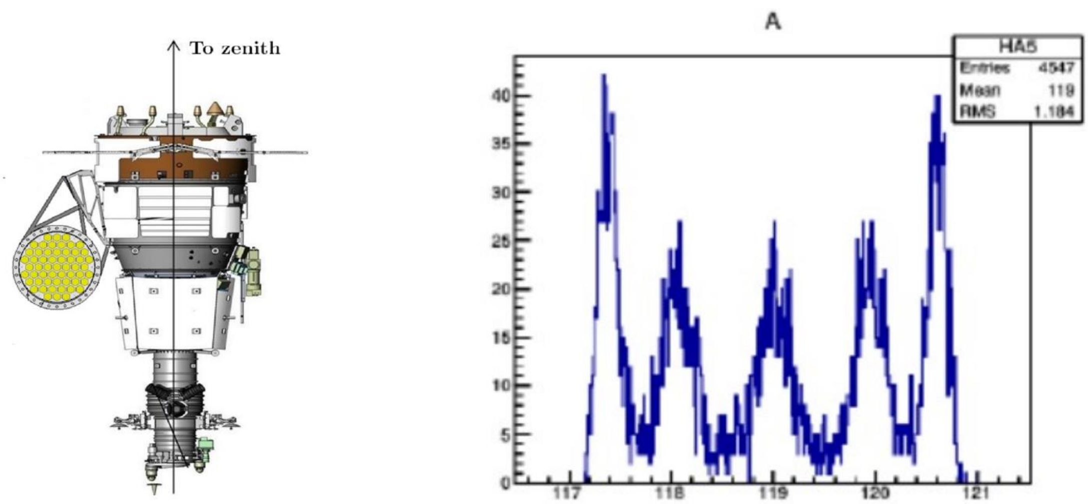


Fig. 71. The expected appearance of the NUCLEON-2 spectrometer and an example of the decomposition of the nuclear flux into isotopes (simulation).

Selected publications

2017 Measuring the Isotopic Composition of Superheavy Nuclei of Galactic Cosmic Rays in the NUCLEON-2 ExperimentKarmanov D.E., Kurganov A.A., Panasyuk M.I., Panov A.D., Podorozhny D.M., Turundaevskiy A.N. Bulletin of the Russian Academy of Sciences: Physics, издательство Allerton Press Inc. (United States), том 81, № 4, с. 401-403 .

2017 Heavy isotopes cosmic ray spectrometer (HICRS) for the NUCLEON-2 mission

Karmanov D., Kovalev I., Kurganov A., Panasyuk M., Panov A., Podorozhny D., Sedov G., Tkatchev L., Turundaevskiy A. Proceedings of Science. The 35th International Cosmic Ray Conference. 12-20 July 2017 Busan, Korea, Proceedings of Science, c. 166

3.2. HERO space laboratory

(Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University)

The main goal of the High-Energy Ray Observatory (HERO) mission (Fig. 73.) is to perform direct measurements of very high energy cosmic ray. Measurements will concern the following scientific goals: detailed study of charge composition of CR in knee region, studies of the energy spectra of Galactic and extragalactic CR, search for signatures of dark matter particles. HERO is planned to be launched onboard a heavy satellite. This experiment is based on the application of a wide aperture (>2π) deep (~5λ) ionization calorimeter. The effective geometrical factor of the apparatus is not less than 8-16 m² sr depending on the type of particles. Under the long exposure (~10 years), this mission will make it possible to precisely measure cosmic rays up to 1017eV. Wide Monte-Carlo simulations were performed to obtain instrument response for different species of cosmic rays, including charged particles and gammas.

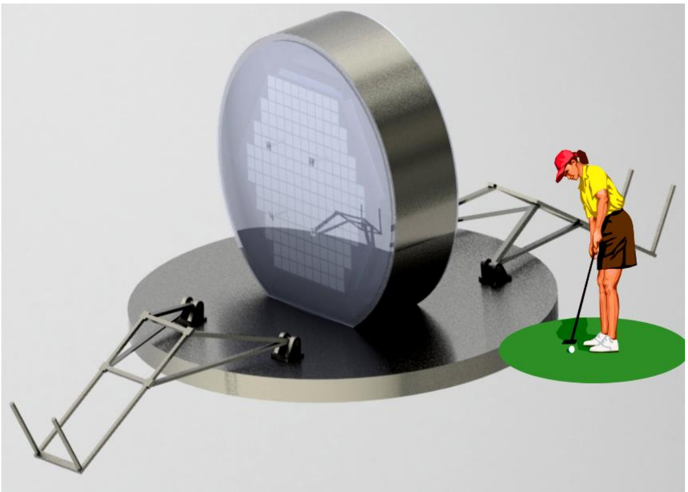


Fig. 72. The expected appearance of the HERO spectrometer.

Selected publications

2017 *The HERO (High-Energy Ray Observatory) simulationTurundaevskiy A., Bakaldin A., Karmanov D., Leonov A., Mikhailov V., Panov A., Podorozhny D.Proceedings of Science. The 35th International Cosmic Ray Conference. 12-20 July 2017 Busan, Korea*

2017*The HERO (High-Energy Ray Observatory) simulation. TurundaevskiyA., BakaldinA., KarmanovD., LeonovA., MikhailovV., PanovA., PodorozhnyD.35th International Cosmic Ray Conference, Busan, Корея, Республика, 12-20 июля 2017*

3.3. KLYPVE -EUSO - ultra-high energy cosmic ray observatory on board the ISS

(Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University)

KLYPVE-EUSO is a mission led by the Russian Space Agency to place an ultra-high energy cosmic ray observatory on board the Russian Segment (RS) of the ISS. The concept of the detector is based on the mirror-type detector proposed by SINP MSU in 2010 and improved by the joint studies with the JEM-EUSO collaboration. In 2017 SIMP MSU have started the conceptual design stage of the project development. To fulfill the requirements of K-EUSO experiment, a Schmidt telescope covering a field of view of 40° with an entrance pupil diameter of 2.5 m, a 4 m diameter mirror and a 1.7 m focal length is being developed. The general view of the camera is shown in fig. 73(right). The baseline variant consists of a spherical mirror, a corrector plate and a spherical focal surface concentric with the mirror, placing the aperture stop on the frontal surface of the corrector plate. The results of the optical system simulations is presented in Fig. 73, left. The very fast relative aperture (F/# 0.7) minimizes the detector size and its obstruction, resulting in a throughput of 70% over the entire field of view. The nominal polychromatic RMS spot size is well inside the dimension of pixel size (3mm) of the multi-anode PMT all over the FOV, providing an angular resolution higher than 2 mrad (corresponding to ground resolution of about 750 m from the ISS orbit).

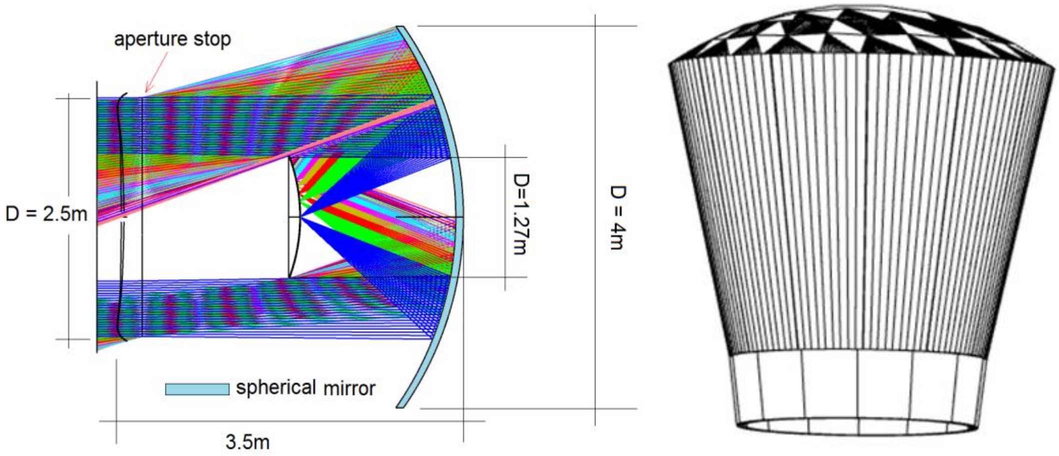


Fig. 73. Left: K-EUSO Schmidt camera optics simulation results. Right:Preliminary 3D model of the K-EUSO Schmidt camera.

The focal surface (FS) of the updated KLYPVE detector utilizes a design similar to that proposed for the JEM-EUSO detector. It will be produced of almost 120 thousand Hamamatsu R11265-103-M64 multi-anode photomultiplier tubes (MAPMTs), grouped into photodetector modules (PDMs). The number of pixels in one MAPMT is 64, the number of MAPMTs in one PDM is 36. The size of a pixel is adjusted to the path length of an extensive air shower during onetime sample (one gate time unit, 2.5 μs). The front-end electronics and high voltage power supply are the same as for the JEM-EUSO. In the Schmidt camera design the FS

has a concave shape with a diameter of 1.27~m and radius of curvature of 1.7~m. There are 52 PDMs on the FS.
The most challenging part of the equipment design is the mechanical structure. The detector is planned to be launched with the “Progress”" cargo which doesn't have the unpressurized compartment. This leads to that all parts of K-EUSO will be first stored inside the ISS and then mounted outside the station during extravehicular activity. In this case all the equipment should be divided into a number of parts whose dimensions will allow these procedures. Another option is usage of another cargo (Space-X Dragon, for example) to avoid the transportation of the detector through the ISS windows. A sketch of the detector mechanical structure in the operation mode and during transportation is shown in fig.74. This design allows the telescope to be transported with minimal number of the separate parts.

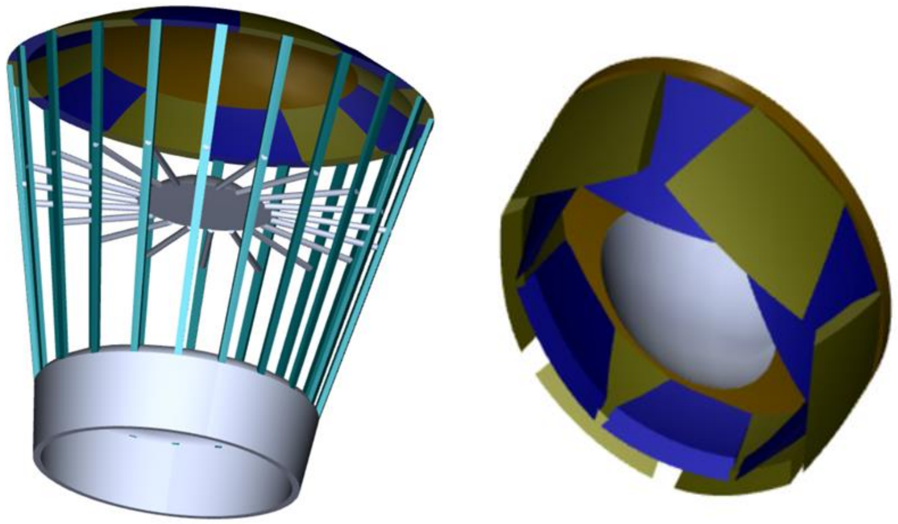


Fig.74. 3D model of K-EUSO mechanical structure. Left: in operation mode. Right: during transportation.

A new Schmidt type optical system allows to increase the Field of View to 40° and makes the experiment competitive with large ground-based observatories, with the advantage of the uniform exposure over the whole celestial sphere. The laboratory models of mirror-concentrator and photo detector module are being developed and manufactured. The launch of the experiment is scheduled to 2022 followed by the installation on the RS of the ISS and at least two years of operation.

Selected publications

M.I. Panasyuk, M. Casolino, G.K. Garipov, T. Ebisuzaki, P. Gorodetzky, B.A. Khrenov, P.A. Klimov, V.S. Morozenko, N. Sakaki, O.A. Saprykin, S.A. Sharakin, Y. Takizawa, L.G. Tkachev, I.V. Yashin, and M.Yu Zotov. The current status of orbital experiments for UHECR studies. Journal of Physics, 632(1):012097, 2015.M. Casolino, P. Klimov, L. Piotrowski. Observation of ultra high energy cosmic rays from space: Status and perspectives. Progress of Theoretical and Experimental Physics (PTEP), 2017(12):12A107, 2017.. G. K. Garipov, M. Yu Zotov, P. A. Klimov, M. I. Panasyuk, O. A. Saprykin, L. G. Tkachev, S. A. Sharakin, B. A. Khrenov, and I. V. Yashin. The klypve ultrahigh energy cosmic ray detector on board the iss. Bulletin of the Russian Academy of Sciences: Physics, 79(3):326–328, 2015. P. Klimov, M. Casolino for the JEM-

EUSO Collaboration. Status of the KLYPVE-EUSO detector for EECR study on board the ISS. In Proceedings of Science (35th International Cosmic Ray Conference), PoS(ICRC2017)412, 2017.M. Casolino, M. Bertaina, A. A. Belov, T. Ebisuzaki, M. Fukushima, P. Klimov, M. I. Panasyuk, P. Picozza, H. Sagawa, K. Shinozaki, the JEM-EUSO Collaboration. KLYPVE-EUSO: Science and UHECR observational capabilities. In Proceedings of Science (35th International Cosmic Ray Conference), PoS(ICRC2017)368, 2017.V. V. Druzhin, D. T. Puryaev, and S. A. Sharakin. Optical system for orbital detector of extreme-high-energy cosmic ray. JOURNAL OF ASTRONOMICAL TELESCOPES INSTRUMENTS AND SYSTEMS, 4(1):014002, 2018.

3.4. UV atmosphere (Mini-EUSO): a compact UV telescope onboard ISS

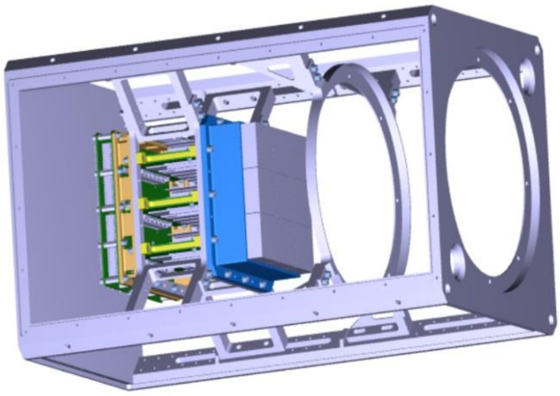
(Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University)

The UV atmosphere (Mini-EUSO) instrument is a UV telescope to be placed inside the International Space Station (ISS), looking down on the Earth from a nadir-facing window in the Russian Zvezda module. Mini-EUSO will map the earth in the UV range (300–400 nm) with a spatial resolution of 6.11 km and a temporal resolution of 2.5μs, offering the opportunity to study a variety of atmospheric events such as transient luminous events (TLEs) and meteors, as well as searching for strange quark matter and bioluminescence. Furthermore, Mini-EUSO will be used to detect space debris to verify the possibility of using a EUSO-class telescope in combination with a high energy laser for space debris remediation. The high-resolution mapping of the UV emissions from Earth orbit allows Mini-EUSO to serve as a pathfinder for the study of Extreme Energy Cosmic Rays (EECRs) from space by the JEM-EUSO collaboration.

In 2016-2017 SINP MSU develops the instrument together with the JEM-EUSO collaboration and RSC ENERGIA.

Mini-EUSO is based on one EUSO detection unit, referred to as the Photo Detector Module (PDM). The PDM consists of 36 multi-anode photomultiplier tubes (MAPMTs), each with 64 pixels, for a total of 2304 pixels. The full Mini-EUSO telescope is made up of 3 main systems, the optical system, the PDM and the data acquisition system. The optical system of 2 Fresnel lenses is used to focus light onto the PDM in order to achieve a large field of view (44°) with a relatively light and compact design, well-suited for space application. The PDM detects UV photons and is read out by the data acquisition system with a sampling rate of 2.5μs and a spatial resolution of 6.11 km.

The current view of the detector during mounting and tests in Tor Vergata University, Rome is shown in Fig. 75.



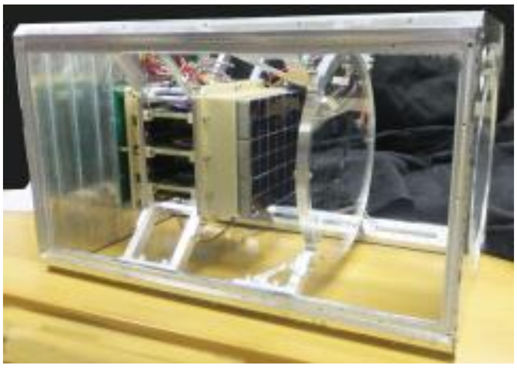


Fig. 75. The UV atmosphere (Mini-EUSO): 3D model (left) and instrument during tests in Tor Vergata University, Rome (right).

Selected publications

Capel Francesca, Belov Alexander, Casolino Marco, Klimov Pavel. Mini-EUSO: A high resolution detector for the study of terrestrial and cosmic UV emission from the international space station. Advances in Space Research, 2017. DOI: 10.1016/j.asr.2017.08.030

V. Scotti, G. Osteria, A. A. Belov, the JEM-EUSO collaboration. The mini-EUSO telescope on the ISS. Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 845:408–409, 2017.

Alexander Belov, Mario Bertaina, Francesca Capel, Federico Fausti, Francesco Fenu, Pavel Klimov, Marco Mignone, Hiroko Miyamoto. The integration and testing of the mini-EUSO multi-level trigger system. Advances in Space Research, 2017. DOI: 10.1016/j.asr.2017.10.044

3.5. UNIVERSAT – SOKRAT space project

(Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University)

The natural and "man-made" space environment together produces serious risks for the implementation of space mission both robotic and human involving. The risk is determined by the planned missions specifics. It consists of mission duration, localization in outer space and parameters of orbits. The specifics of the natural environment in outer space (a variety of physical parameters of the radiation fields, features of the ballistic trajectories of natural space objects), as well as human activity effects (man-made debris pollution in outer space) make the real difficulties for their modeling and risk calculation, as a rule. The real-time monitoring of natural and man-made space objects (potential threats) is the best and most effective way to reduce the risks.

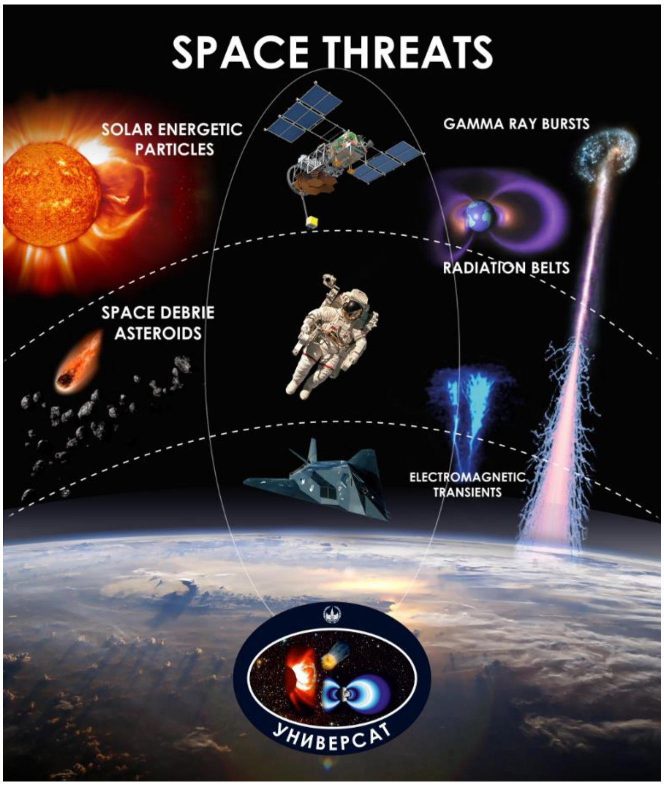


Fig. 76. The principal goals of the UNIVERSAT – SOKRAT project.

Project mission is to develop a satellites constellation for real-time monitoring of near-Earth treats in space. It means monitoring of:

- radiation environment;
- potential dangerous objects of nature (asteroids, meteors) and man-made (space debris) origin;
- electromagnetic transients;

Success in project realization allows: for the first time in the world to create a prototype of space monitoring and space threats prevention system for both ongoing and planned space missions, including high-altitude atmospheric aircrafts; to create the new and innovative technologies in the sphere of instrumentation and methods for solving information problems in real time; to develop a new educational standards and specialist training methods in the new field of applied space researches.

Selected publication

Optimization of measurements of the Earth's radiation belt particle fluxes.Panasyuk M.I., Podzolko M.V., Kovtyukh A.S., Brilkov I.A., Vlasova N.A., Kalegaev V.V., Osedlo V.I., Tulupov V.I., Yashin I.V. Cosmic Research (English translation of Kosimicheskie Issledovaniya), издательство Maik Nauka/Interperiodica Publishing (Russian Federation), 55, № 2, с. 79-87, 2017

3.6. Hydroxyl experiment on board the International Space Station
(Russian Academy of Sciences, Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN))

The Hydroxyl experiment on board the Russian Segment of the International Space Station (RS ISS) is aimed at optical diagnostics of the upper atmosphere for monitoring atmospheric conditions and predicting geophysical disasters. Within the framework of the experiment, a set of specialized scientific equipment – a spectrophotometric complex (SPC) – has been designed in cooperation with the Institute of Applied Physical Problems of the Belarusian State University. The complex will form part of the multi-purpose laboratory module (MLM) of RS ISS. The equipment has passed ground tests and will be delivered to RS ISS in 2017.

When we measure emission of the upper atmosphere from board an orbiting station in the direction of the Earth's limb, the effective thickness of the layer and, hence, its emission increase about 30 times as compared to what it appears to the observer on the ground. This is an important advantage of optical measurements on board the ISS.

The spectrophotometric complex (SPC) ensures high-resolution (~1 nm) measurements of absolute intensities of the hydroxyl emission in the range of 830-1040 nm and green-line emission of the atomic oxygen at the wavelength of 557.7 nm. It also provides data on spatial distribution of these emissions in the range of altitudes 80-110 km with a spatial resolution in height no worse than 1 km.

The onboard SPC equipment (see Fig.1 for general view) comprises an optical unit (OU) - 1, an electronics unit (EU) – 2, and a bracket - 3 for mounting the OU on the window of the MLM pressurized mating adapter.

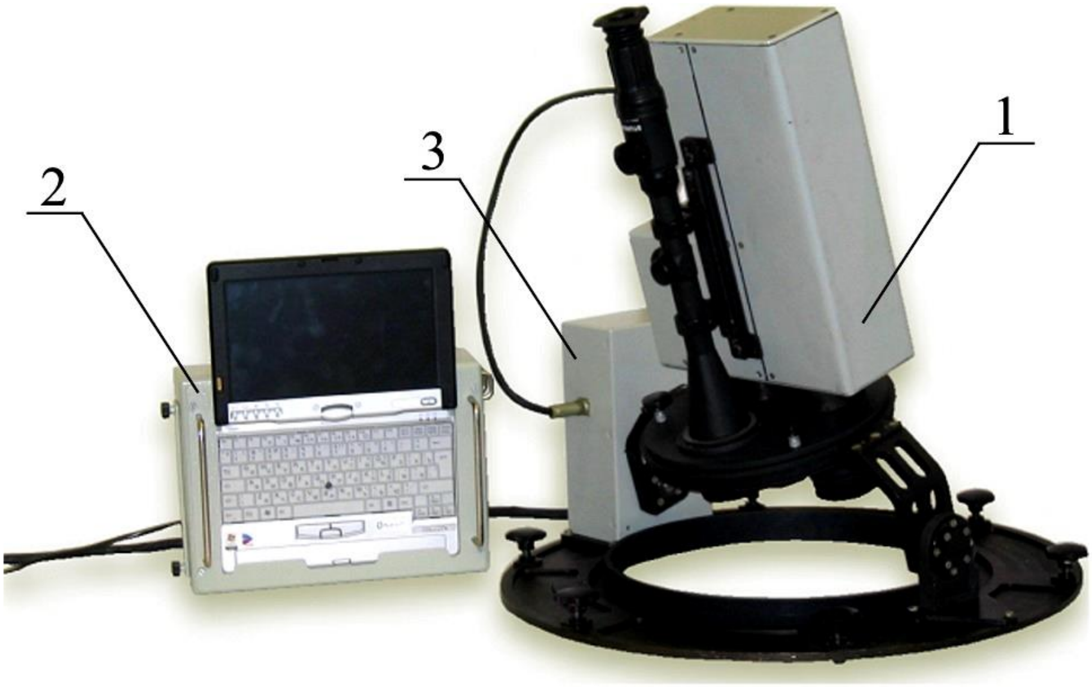


Fig.1.SPC overall view.

The main specifications of the spectrophotometric complex are:

Working spectral range of the spectral imaging module (SIM), nm	830-1040
Working spectral range of the oxygen emission recording module (ERM), nm	557.7
Spectral resolution no worse than, nm	1,0
Spatial resolution in height, km	1,0
Field of view vertical angle, degree	3
Minimum recorded emission, Rayleigh	20
Measurement interval for emissions, s	1-100

The complex operates in the following mode:

- test/calibration of the SPC optical unit;
- recording spectral images of hydroxyl emissions;
- recording spatial distribution of the atomic oxygen emission;
- transfer of scientific and service data to the onboard telemetry and control system of the RS ISS service module.

Initially, the operator points the optical unit at the object (the region of oxygen and hydroxyl emissions at the height of 80-93 km) with an optical sight by matching the hair-line with the horizon. Afterwards, the tracking of the object is performed automatically in the measurement mode. Figure 2 shows the geometry (collage) of pointing the equipment at a region at a height of about 100 km.

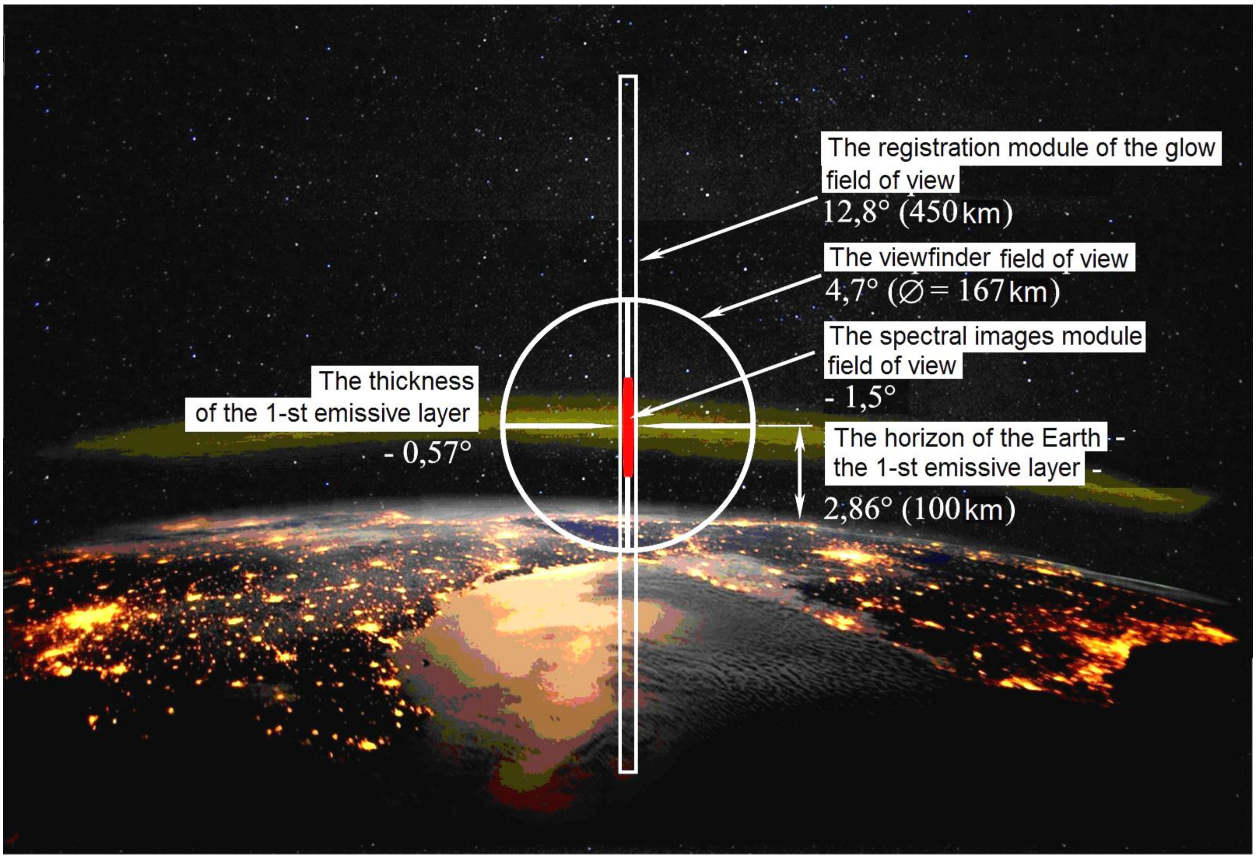


Fig.2. Fields of view of the optical sight; the spectral imaging and oxygen emission recording modules of SPC (collage).

Despite a great practical significance and almost 50 years of research, the kinetic mechanism of the hydroxyl emission is still quantitatively unclear, and the available rate constants of chemical reactions involving hydroxyl radicals are defined at the temperature of 300ºK. This is significantly higher than the mesospheric temperature (130º to 250ºK), which severely limits the scope of the hydroxyl emission for practical purposes.

The need for space experiments is determined by the significance of hydroxyl radiation both from the point of view of studying the dynamics of chemical interactions between the hydroxyl (OH) and the major constituents of the atmosphere (N2, O2, and O), and from the standpoint of various applications of these data.

The efficiency of the Hydroxyl space experiment will be determined by the scientific results obtained and conclusions drawn from the measurement data, in particular:

- creating an empirical model of the intensity distribution of hydroxyl and oxygen emissions under the given helio- and geophysical conditions;
- using empirical laws for the development of a theoretical model based on the kinetic mechanism of the hydroxyl emission and supported by observations of the hydroxyl (OH) and oxygen emissions on board the RS ISS;
- determining the tendency of global changes in the atmospheric parameters and their relationship with the evolution of solar activity and anthropogenic processes;
- developing an algorithm of earthquake prediction based on the records of hydroxyl (OH) and atomic oxygen green-line (557.7 nm) emissions over seismically active regions.

3.7. Space experiment TAHOMAG-MKS

(Russian Academy of Sciences, Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN))

Within the framework of the Federal Space Program for the space experiment TAHOMAG-MKS, scientific equipment is being developed for placement on the Russian segment of the International Space Station.

The space experiment TAHOMAG-MKS (multifunctional optical complex) is designed to solve the following problems:

- detailed and accurate studies of the dynamics of magnetic fields in the solar photosphere and chromosphere with spatial resolution inaccessible to ground-based observations; -

- Monitoring of the most geoeffective phenomena of solar activity, such as large solar flares and ejections of coronal plasma towards the Earth.

At present, work is underway to produce a model of the device and create a test bench.

3.8. Radio spectrometer-detector for the Interhelioprobe mission

(Russian Academy of Sciences, Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN))

A radio spectrometer-detector (RSD) intended for continuous monitoring of the heliosphere and detection of different-type solar radio bursts in the frequency range of 15 kHz – 300 MHz by the method of radio frequency spectrometry was developed within the framework of the Interhelioprobe Project. The scientific objectives of the experiment involve the study of radio emissions in the meter, decameter, hectometer, and kilometer wavelength ranges; II-, III-, and IV-type radio bursts, interplanetary magnetic field, processes in the solar corona and interplanetary medium, as well as solar flares and flare-generated shocks and mass ejections.

3.8.1. Description of RSD instrument

The radio spectrometer-detector (RSD) has three identical receiving channels for measuring three components of the electromagnetic-field vector.

Each channel comprises:

- antenna (asymmetric vibrator) and antenna amplifier;
- two channels *(reservation)* for direct signal amplification with the adjustable transmission coefficient;
- two analog-to-digital conversion modules (*reservation*);
- digital processor of signals.

Main characteristics of RSD channels:

- threshold sensitivity, no less than 160 dB/Hz
- dynamic range without amplification adjustment, no less than 80 dB
- dynamic range of amplification adjustment, no less than 120 dB
- working frequency range from 15 kHz to 300 MHz

Spectral resolution:

- in the frequency range from 15 kHz to 30 MHz, no more than 15 kHz
- in the frequency range from 30 MHz to 150 MHz, no more than 30 kHz
- in the frequency range from 150 MHz to 300 MHz, no more than 74 kHz.

Specifications of the RSD instrument:

- time resolution, no more than 0.1 s
- maximum frequency of measurements, no more than 10 Hz
- internal memory, no less than 256 MB
- volume of measurement data 16384 byte
- data transmission rate, no less than 1 Mbit/s
- size of the receiver unit 192x161x59 mm
- mass of the receiver unit 1.4 kg
- mass of each of the 3 antennas 300 g
- direct-current supply voltage 24-29 V
- maximum power consumption, 10 W.

3.8.2. RSD design

The antenna (see Fig.1) of each channel consists of a skeleton boom 800 mm long, an amplifier unit, and a vibrator ribbon 500 mm long

The vibrator ribbon is a strained, shaped ribbon of stainless steel. In the normal position, it is fixed at the angle of 30º to the boom axis.

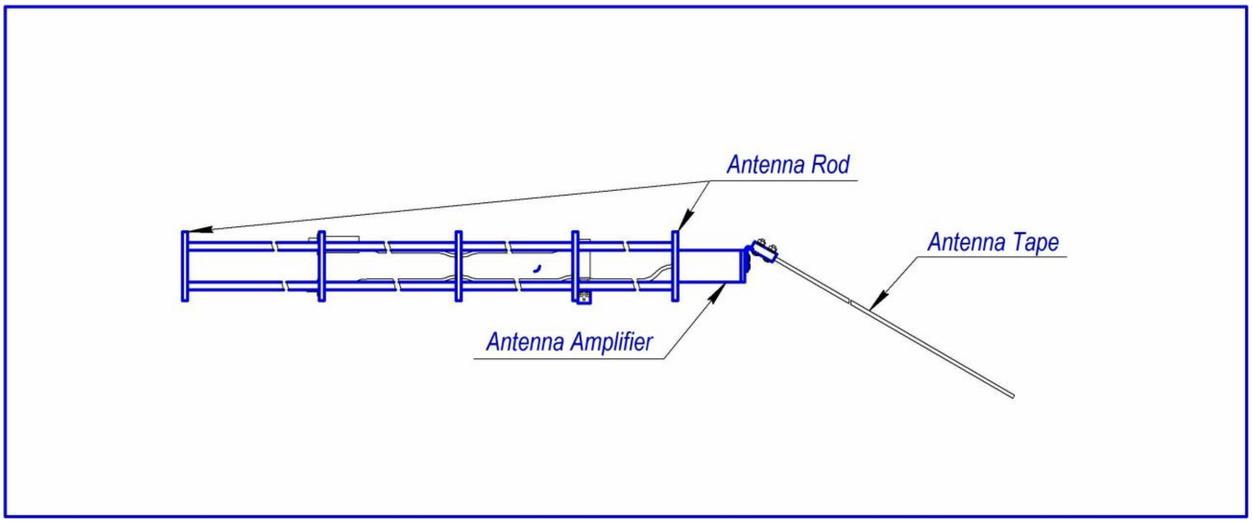


Fig.1. Design of the RSD antenna-feeder assembly.

The thermal equivalent and full-scale prototype (mock-up) of the RSD receiver are illustrated in Fig.2.

Fig.2.General view of the RSD receiver. Thermal equivalent (top). Full-scale prototype (bottom).

A possible mutual position of the antennas on the spacecraft body is shown in Fig. 3. In this geometry, the orthogonal components of the electromagnetic field can be obtained from the following relations:

a1 = **x**·cos(30º) **-** **z**·sin(30º);

a2 = -**x**·cos(45º) - **y**·cos(45º) - **z**·sin(30º);

a3 = -**x**·cos(45º) + **y**·cos(45º) - **z**·sin(30º)

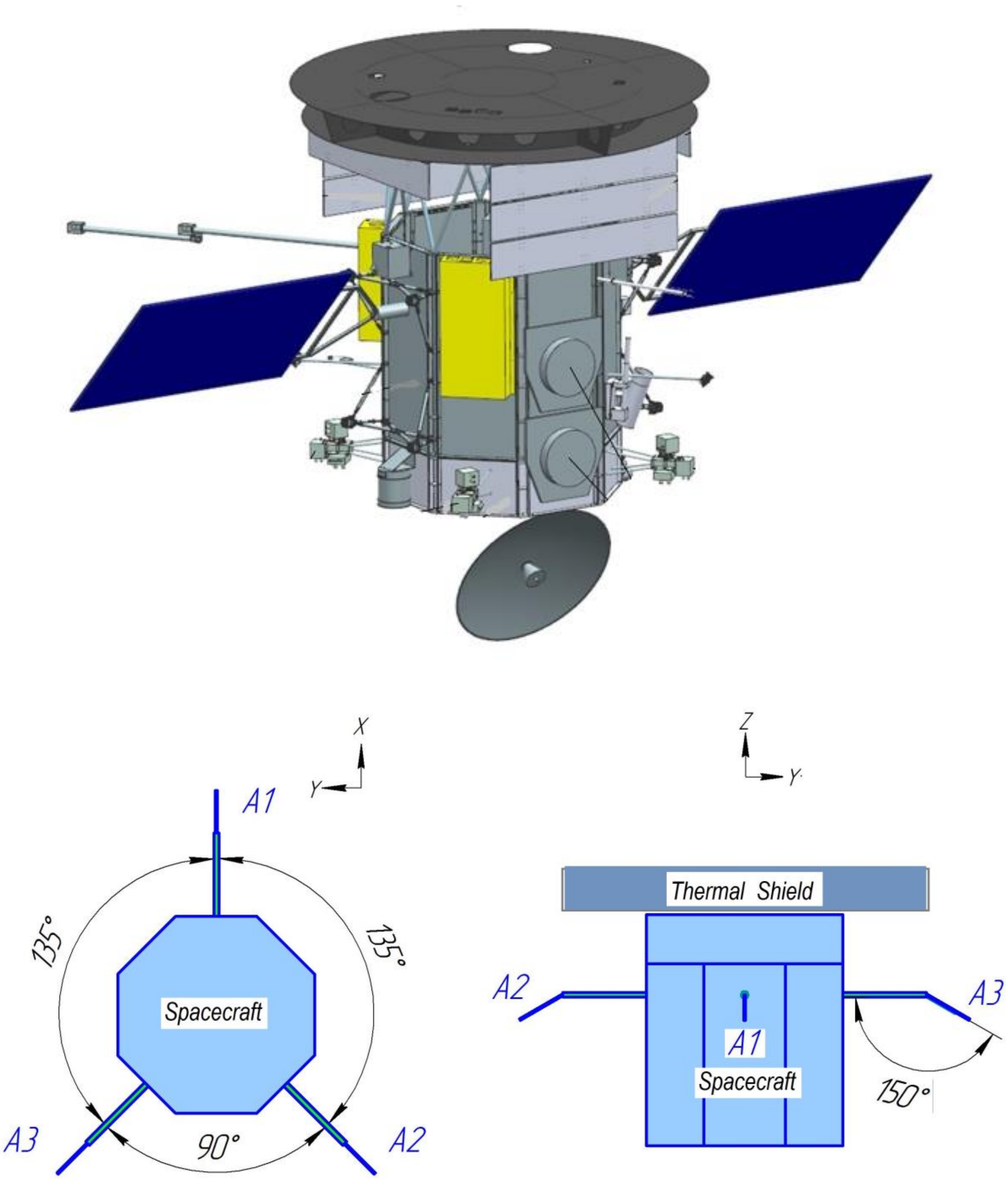


Fig.3.Possible disposition of the RSD antennas on the Interhelioprobe body.

3.9. Sura-ISS complex ground-based and space experiments in 2017

(Russian Academy of Sciences, Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN),
Central Research and Engineering Institute)

The objectives of the experimenpts carried out in 2017 included: the forecast of geo- and heliophysical conditions in the ionosphere, the choice of the heating modes with a minimum critical frequency of F2 layer of the ionosphere, analysis of the results of radio sounding of the ionosphere and measurements of geomagnetic disturbances on the ground, estimation of the efficiency and probability of artificial effects on the ionosphere, and finding correlations between the geomagnetic field variations and the Sura emission program. Experiments with a new combination of the heating conditions (on-off periodicity, exposure time, two-frequency and continuous heating, variations in the emission power, polarization, direction of HF radiation, etc.) were carried out in the intervals between the recurrent magnetic storms. The experiments revealed geomagnetic pulsations and substorm effect stimulated by the SURA facility (in accordance with the cyclogram) against the background of quiet geophysical conditions.

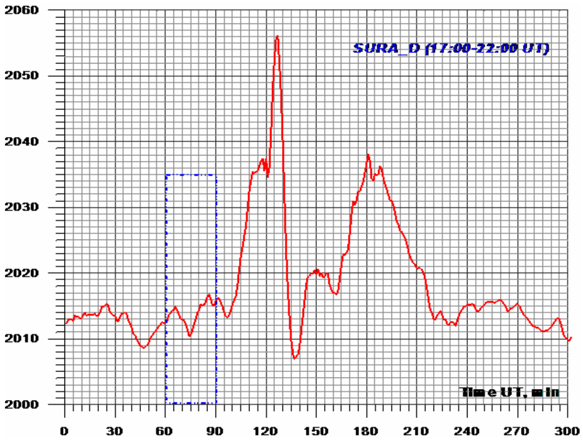


Figure 1. Horizontal component of the geomagnetic field – the substorm triggered by the Sura facility on 20 September 2017.

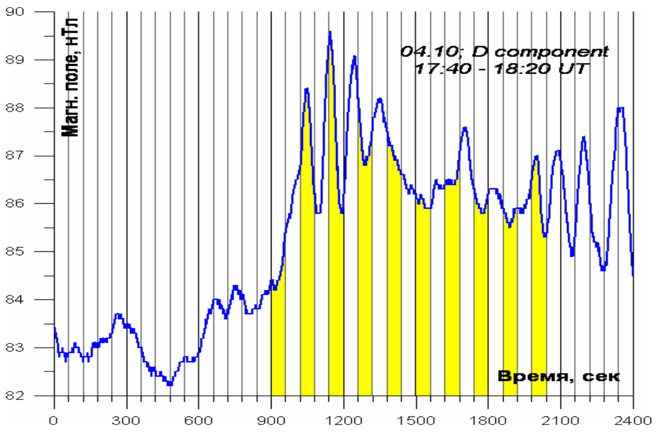


Figure 2. Geomagnetic pulsations – a 40-min fragment where the colored bars correspond to ten HF pulses stimulating the ionosphere within the frames of the Sura program.

Selected publication

Ю.Я. Ружин, В.С. Докукин, В.Д. Кузнецов, Ю.А. Пластинин. «Комплексные наземно-космические эксперименты Сура-МКС 2017 года.» VIII Всероссийские Армандовские чтения [Электронный ресурс], Муром, 2018, стр.60-67. ISSN 2304-0297 (CD-ROM)

Ружин Ю.Я., В.Д. Кузнецов, Ю.А. Пластинин. «Эффекты, стимулированные стендом СУРА по программе 2017г. геофизических экспериментов на МКС». //Геомагнетизм и аэрономия. Т. 58. № (принято к печати). 2018

3.10. ARKA space complex designed to obtain solar corona images and transient layer of the Sun using spectral lines in the vacuum ultraviolet (VUV) spectral range.

(Russian Academy of Sciences, Lebedev Physical Institute (FIAN))

The Russian Federal Space Program provides for the development and orbit injection of a new space solar observatory under the code name ARKA by 2025. The device will operate near the Earth on the sun-synchronous orbit and will be observing the Sun continuously.

The project provides for the orbit injection of 3 scientific instruments, including two solar telescopes with the highest space resolution in the world, better than 100 km, which is several times higher than the resolution provided now by NASA's Solar Dynamics Observatory (SDO). A small telescope to observe the solar disc and solar space within the altitude band up to 1 solar radius will be the third instrument of the satellite. Such range of equipment will make it possible to study both the processes on the surface of the Sun and inside its outer layers. In particular, coronal mass ejections, being the main reason for changes in space weather, will be observed at their earlier stages.

Both telescopes of the project are two-mirror instruments built in accordance with Ritchey-Chretien scheme. The first telescope will operate in 171 Angstrom ferrum spectral line and will observe the solar corona. The second telescope will operate in 304 Angstrom helium line and will observe transient layer of the Sun.

Record-breaking space resolution of the telescopes will be achieved by means of specific features of their optical arrangement: the telescopes will observe the Sun in a restricted field of view but with in extremely high details. The field of view will be 10x10 arc minutes which is equal to 1/7 of the solar disc area. The size of the telescope detectors registering the images will be 6000x6000 pixels. Such combination of the limited field of view and large size of detectors will make it possible to distinguish objects with the size of 75 km on the Sun surface for the first time ever.

Several Russian companies are engaged in the project. Lebedev Physical Institute of the Russian Academy of Sciences leads the project. Main electronic and mechanical units will be developed and final assembly of the apparatus will be carried out in the Institute. X-ray optics and filters for telescopes will also be manufactured at the Russian Institute for Physics of Microstructures. Supersmooth mirrors dia. 300 mm have already been developed for the project. Thermally stable titanium-based alloys, which are also being manufactured in Russia, will be used in the telescope structure. In general, about 80% of scientific gear and instruments were manufactured in Russia.

The most important foreign contribution to the project is CCD detectors specially designed for this mission by UK company e2v. The size of the detectors exceeds 6000x6000 elements. These are the largest matrices ever used in space solar missions.

The development is expected to be completed in 2021 (flight model of the spacecraft will be developed). According to the Federal Space Program, the spacecraft is planned for launch in 2023.

The project is open for scientific and technical cooperation.

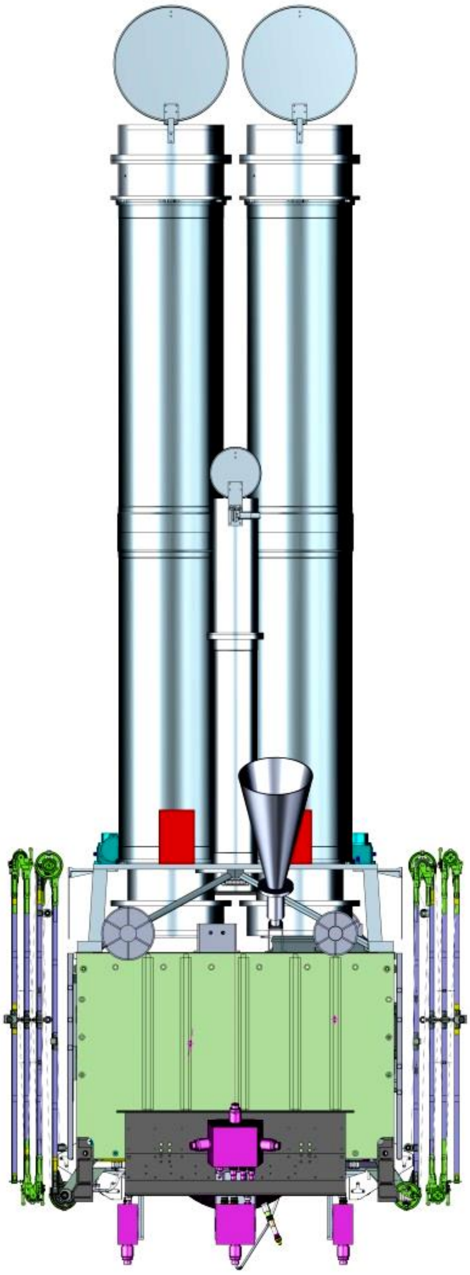


Figure 3.1. Layout of ARKA spacecraft.

3.11. "World Space Observatory - Ultraviolet" ("Spektr-UF")
(Russian Academy of Sciences, Institute of Astronomy (INASAN))

The project "Spektr-UF" (international name "World Space Observatory - Ultraviolet") will provide astrophysicists with an opportunity to study various objects of the universe in ultraviolet (UV) spectral range, 115-310 nm, that is unreachable by ground-based instruments. The scientific payload of the observatory "Spectrum-UV": telescope T-170M with a main mirror diameter of 1.7 m, high- and low-resolution spectrographs, camera for high quality images in the UV range, and an instrument for registration gamma- radiation from space objects «Konus-UF». The launch date is 2024.

Scientific tasks

Main scientific tascs of WSO-UV are:

a) high resolution (spectral resolving power $R \geq 50\ 000$) spectroscopy of the point sources by means of two echellé spectrographs covering the 115–310 nm spectral range;

b) long slit (1x75 arcsec) low resolution (spectral resolving power $R \sim 1000$) spectroscopy of extended and faint point sources with a near-UV channel and a far-UV channel to cover the 115–305 nm spectral range;

c) near-UV and a far-UV direct imaging with angular resolution up to 0.08 arcsec in the full 115–320 nm spectral range to study the structure of extended objects as well as photometry of such objects.

Characteristics of WSO-UV payload

The observatory includes a 170 cm aperture telescope capable of high-resolution spectroscopy and long slit low-resolution spectroscopy with the WUVS (WSO-UV Spectrographs) instrument; moreover UV imaging will be available with the Field Camera Unit (FCU) instrument. Additional payload for WSO-UV is “Konus-UF” instrument.

The telescope T-170M is a Ritchey-Chrétien with a F/10 focal ratio and a corrected field of view of 0.5 degrees. The T-170M telescope is one of the most improved parts of the mission. The telescope passed its vibration, static, transportation tests as well as thermal-vacuum tests.

Fig.1.General view of the T-170M telescope.

The WSO--UV spectrographs (WUVS) consists of a set of three instruments:

- The far UV high resolution spectrograph that will permit to carry out echellé spectroscopy with resolution about 50000 in the 115—176 nm range.
- The near UV high resolution spectrograph to carry out echellé spectroscopy with resolution about 50 000 in the 174—310 nm range.
- The Long Slit Spectrograph that will provide low resolution (R=1000), long slit spectroscopy in the 115—305 nm range. Thespatialresolutionwillbe 0.5 arcsec.
-

All spectrographs will be equipped with a CCD.At the moment (May 2018) the Instrument is at the level of EQM construction.

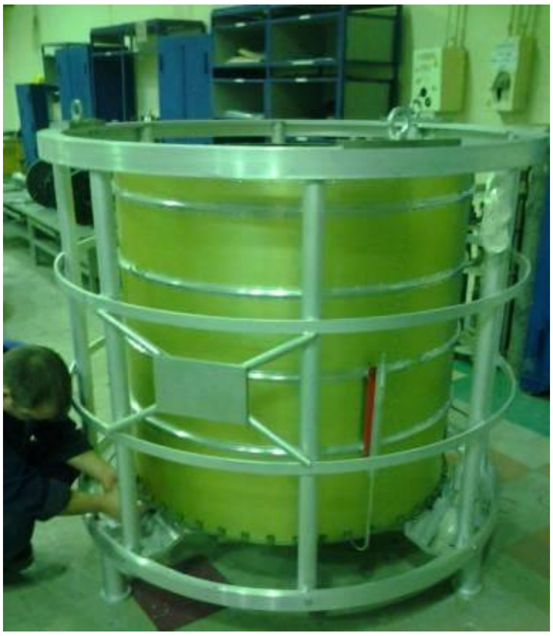


Fig.2.Structural – thermal model of WUVS instrument.

Рис.3. Electrical model of WUVS instrument.

The Imaging instrument, Field Camera Unit (FCU), will be an important part of the WSO-UV instrumentation. It is the first UV imager to be flown to high Earth orbit, above the Earth geocorona. FCU hastwochannels:

- The Near Ultraviolet channel: covering wavelengths in the 174–310 nm interval. Field of view is 597x451 arcsec., angular resolution is about 0.146 arcsec. Detector is CCD.;
- The Far Ultraviolet channel: working in the range 115–176 nm. The field of view is 121x121 arcsec.,angular resolution is about 0.08arcsec. Detector is MCP.

FCU is being developed by Russia and Spain. There is a strong interest of Mexican and Japanese astronomical community to participate in FCU.

Additional payload for WSO-UV is “Konus-UF” instrument for GRB studies in 10 kev to 10 Mev range. It is an analogue of the instrument described in the paper by Aptekar et al. (Aptekar, R. L.; Cline, T. L.; Frederiks, D. D.; Golenetskii, S. V.; Mazets, E. P.; Pal'shin, V. D. “Konus-Wind Observations of the New Soft Gamma-Ray Repeater SGR 0501+4516”. TheAstrophysicalJournalLetters, Volume 698, Issue 2, pp. L82-L85 . 2009)

Planned scientific experiments with WSO-UV

The science management plan of WSO-UV was presented in the paper (Malkov O., ·Sachkov M., Shustov B.,· Kaigorodov P.,· Yáñez F.J.,· Gómez de Castro A.I. Scientific program construction principles and time allocation scheme for the World Space Observatory—Ultraviolet mission// Astrophysics and Space Science, 2011, 335, pp323-327) . WSO-UV will work as a space targeted observatory with a Core Program described here, an Open Program for scientific projects from the world-wide community and national (Funding Bodies) programs for the project partners.

The key scientific drivers of the WSO-UV project are:

1. The determination of the diffuse baryonic content in the Universe and its chemical evolution. The main topics will be the investigation of baryonic content in warm and hot Inter Galactic Matter, of damped Lyman-alpha systems, the role of starburts and the formation of galaxies.

2. The physics of accretion and outflows: stars, black holes, and all those objects dominated by accretion mechanisms. The efficiency and time scales of the phenomena will be studied, together with the role of the radiation pressure and the disk instabilities.

3. The study of the formation and evolution of the Milky Way. The Milky Way history could be tracked through observations complementary to those obtained by the GAIA mission.

A special attention will be paid to studies of extrasolar planetary atmospheres and astrochemistry in presence of strong UV radiation fields.

Planned scientific experiments with WSO-UV are described in details in the paper by Boyarchuk et al. (2016, Scientific problems addressed by the Spektr-UV space project (world space Observatory—Ultraviolet), Astronomy Reports, Volume 60, Issue 1, pp.1-42)

3.12. KONUS-UF experiment on cosmic gamma-ray bursts and soft gamma-repeaters studies onboard 'Specter-UF' spacecraft

(Russian Academy of Sciences, Ioffe Physical- Technical Institute)

KONUS-UF experiment on cosmic gamma-ray bursts and soft gamma-repeaters study is planned to be carried out onboard 'Specter-UF' spacecraft starting in 2015yr. Its main purpose is the research of cosmic gamma-ray burst and their rare class – sources of repeating soft gamma-ray bursts which were discovered in earlier experiments by Ioffe Institute and were named gamma-repeaters (SGRs). All these phenomena are originated from extremely high explosive energy release of electromagnetic emission the nature of which is one of the most important unsolved problems in astrophysics. Reliable and adequate for this purpose the scientific instrument KONUS was designed by Ioffe Institute and has been uninterruptedly operating for 17 years onboard American spacecraft 'Wind'. Joint Russian-American experiment KONUS-WIND yields light curves, energy spectra and data on fast spectral variability of gamma-ray bursts. These data are widely called for in complex multiwave investigations of the phenomena by international network of space and ground-based telescopes. For such observations the strongly elongated Wind's orbit with apogee at 0,5 – 1,5 mln. km is exceptionally favorable, the orbit provides a survey of the entire celestial sphere without substantial losses of information while crossing radiation belts near perigee. Distant from Earth orbit of 'Specter-UF' spacecraft is optimal for such kind of studies too. The KONUS-WIND Russian-American experiment by importance, quality and completeness of the obtained information has come to the forefront of studies of the most powerful explosive events in the universe. The aim of the new experiment is to continue these studies after the flight program of KONUS-WIND experiment has been completed.

To realize the experiment, based on the capabilities of 'Specter-UF' spacecraft, there was proposed a system consisting of one electronic unit 'KONUS-UF-BE' and two detector units 'KONUS-UF-D' with 2π steradian field of view relatively to the detectors' axis of symmetry. Placement of the detector blocks on the coupling girder between the base module NAVIGATOR and scientific equipment complex of 'Specter-UF' spacecraft T170 telescope provides indispensable for the experiment opportunity to survey each celestial hemisphere by one of two detector units.

The scientific instrument for the experiment is a scintillation gamma-spectrometer consisting of two identical detectors and an electronic unit to register and to preprocess signals from the detectors. Each detector contains high-tech spectrometric crystal NaI(Tl) 130 mm diameter and 75mm height inserted in thin-walled aluminum container with the beryllium entrance window and PMT-side window of high transparent lead glass to protect the crystal from background radiation in soft specter band coming from the spacecraft. Such design of the detector gives the low energy registration threshold of 10 keV, gamma-radiation registration range is up to 10MeV with the energy resolution 8,5 – 9,0 % at 660 keV Cs137 line and burst detecting sensitivity
10^{-7} erg sm^{-2}. The detectors of KONUS-UF instrument have no analogues in world practice of cosmic gamma-ray burst registration.

Organization of measurement of gamma-ray burst characteristics in the KONUS-UF experiment is the development of approaches and methods applied in the KONUS-WIND experiment. It is distinguished by being much more informative through the usage of modern element base on digital signal processors, precision analogue-digital converter with low “dead” time and high capacity RAM chips. In background mode each detector performs measurements of cosmic gamma-ray emission intensity in twelve energy bands from 10keV to 1MeV with accumulation time 1s and in ten energy bands from 280keV to 10MeV with accumulation time 4s. Simultaneously in the background mode the detailed measurements of emission spectra are carried out in two energy bands 10keV-1MeV and 280keV-10MeV, those bands are divided in 112 and 154 quasi-logarithmic channels respectively. Spectra accumulation time in the background mode is 1 minute. In a burst mode the intensity of emission is measured in the same energy bands with the time resolution from 100 ms to 2 s. In the instrument there is a special ‘integral’ channel provided for the research of particularly rare extremely intensive giant bursts from gamma-repeaters. The instrument offers extensive opportunities to adjust the gain of linear paths by the set of digital commands. KONUS-UF instrument has the weight 25kg, the power consumption 10-12W, the daily volume of telemetry information 200Mb.

The KONUS-UF experiment is the necessary step towards further highly efficient development of national research program in this actual field of space astronomy.

3.13. The development of mathematical models for analysis of flight trajectories and schemes for performing dynamic operations of perspective spacecrafts. The “Interheliozond” project.
(Russian Academy of Sciences, Keldysh Insitute for Applied Mathematics)

In the Russian cosmic project "Interheliozond" to put SC on a heliocentric orbit close to the Sun (the perihelion radius should fall within the range of 60-70 solar radii) with the maximum possible inclination relative to the solar equator is the main task. When designing a space complex for the implementation of the project "Interheliozond" it is necessary to take into account the following important features:

-high accuracy of bringing the spacecraft to the planet, about a unit of kms;

-large asymptotic velocity of the spacecraft relative to Venus about half of planets orbital velocity, in comparison with its values, according to the accumulated experience of previous flights in which it did not exceed 3.5 km / s.

In order to ensure effective Interheliozond project mission design, advanced formulas for changing the inclination of the spacecraft's orbit when gravitational maneuvers near the planet are committed are obtained to the general case of elliptical orbits of not only the spacecraft but also the planet. The adequate geometric interpretation of the obtained formulas is developed. Expressions are found for the coordinates of the point of maximum possible inclination on the invariant sphere of the asymptotic velocity of the space vehicle. A comparative analysis of the obtained results and modern descriptions of spatial models of gravitational maneuvers by NASA and ESA specialists is carried out. The procedure for constructing a chain of gravitational maneuvers to achieve the geometrically acceptable maximum of the spacecraft's orbit inclination analytically is developed. As a result, the formalized structure of chains of gravitational maneuvers increasing the inclination of the spacecraft's orbit to the ecliptic allows to construct mission design by universal adaptive synthesis of beams of the corresponding optimal trajectories.

Performed results are displayed in publications:

1. *Golubev, Y.F., Grushevskii, A.V., Koryanov, V.V., Tuchin, A.G., Tuchin, D.A. A technique for designing highly inclined spacecraft orbits using gravity-assist maneuvers // Doklady Physic. 2017. T.472, №4. doi:10.7868/S0869565217040090.*
2. *Golubev, Y.F., Grushevskii, A.V., Koryanov, V.V., Tuchin, A.G., Tuchin, D.A. Formation of high inclined orbits to the ecliptic by multiple gravity assist maneuvers // Journal of Computer and Systems Sciences International. 2017. №2. doi: 10.7868/S0002338817020081.*
3. *Grushevskii, A., Golubev, Y.F., Koryanov, V., Tuchin, A., Tuchin, D. To the high inclined orbit formation with use of gravity assists // Advances in the Astronautical Sciences. 2017. №161, pp. 417-434.ISSN: 00653438. ISBN: 9780877036432*

3.14. The descriptions of space experiments for Earth observation, which are in the preparation stage of scientific instrument development and implementation. (Russian Academy of Sciences, Kotel’nikov Institute of Radiotechnics and Electronics (IRE))

Table 1. Earth Observation Space Experiments (SE) on Russian Segment of International Space Station (preparation stage)

	SE	SE objective	Scientific instrument	Start/Finish mission
1	**«Veter»** Determination of the velocity vector of the wind and the wave spectrum of the World Ocean from measurements of the Stokes parameters of microwave radiation with the ISS RS Kotel'nikov IRE RAS	Development of techniques for the identification and acquisition of new experimental data on the spatial characteristics of the vector wind speed and wave spectrum of the oceans by measuring the Stokes parameters of radio microwave radiation of the sea surface	Microwave radiometers, polarimeters 0.8 and 2.25 cm	2022/2023
2	**«Driada»** Measurements of near-IR absorption spectra of the earth's atmosphere and recovery of greenhouse gas concentrations IKI RAS	Measurements of carbon dioxide CO_2 and methane CH_4 in the atmosphere to understand the role of natural processes and human activities that determine the atmospheric content of CO_2 and CH_4	High-resolution IR spectrometer + video camera	2020/2022
3	**«Klimat»** Development of the technology of space monitoring of climate-forming factors of the Earth on the basis of the instrument complex for measuring the content of aerosols, ozone and greenhouse gases in the troposphere and the lower stratosphere IGCE ofRoshydromet and RAS	Testing of scientific and technical methods tomeasure and to monitor changes of climatic factors in the atmosphere (the troposphere, the lower stratosphere) with (nadir and limb observations). Obtaining observational data on changes in climate-forming factors (aerosols, greenhouse gases, ozone) in the Earth's atmosphere (troposphere, lower stratosphere) and the variability of the main components of the energy (radiation) balance of the Earth's climatic system	High resolution Fourier IR spectrometer Monochromatic cameras - MIK 555.7 and MIK 630	2022/2024

	SE	SE objective	Scientific instrument	Start/Finish mission
4	**«Konvergentsiya»** Retrieval of detailed temperature and humidity atmosphere profiles in the study of the genesis of atmospheric disasters. IKI RAS	The study of bases of origin and evolution of large-scale crisis atmospheric processes like typhoons and tropical cyclones as one of basic elements in formation global mass and moisture exchange in system the ocean - atmosphere, measurement of absolute radio brightness temperatures of system the atmosphere - ocean of tropics in the range of 6 … 220 GHz, definition of detailed profiles of temperature and humidity of the atmosphere, carrying out researches on the round-the-clock detection of flashes of lightnings, definition of power, spatial and temporary characteristics of flashes oflightnings, definition ofareas of storm activity	MW scanning spectrometer (MRS); Lightning detector (DM)	2021/2024
5	**«Metrad»** Radio holographic monitoring of the atmosphere, ionosphere and surface Kotel'nikov IRE RAS	Sounding of the atmosphere, ionosphere and Earth's surface by means of highly stable signals from navigation satellites GLONASS/GPS for global monitoring of an ionosphere, the atmosphere and the Earth's surface	Radio occultation receivers	2022/2023
6	**«MKS-Glonass»** Radio sounding of the ionosphere by radio-tomographic and radio-occultation methods IPG	Investigation of the structure and dynamics of the ionosphere by means of a combined use of radio-tomographic (PT) and radio-occultation (RO) methods with terrestrial and satellite radio reception	Two-channel receivers of radio signals with L-range antennas; blocks of transmitters (BPR-1 and BPR-2); blocks of data collection (BSD-1 and BSD-2) with special software	2020/2021
7	**«MKS RSA (P)»** Development of methods for remote sensing of the Earth's surface in the P-band using a	Investigation of possibilities of remote sensing Earth's surface from space using polarimetric SAR in long UHF band (wavelength is about 70 cm)	P band SAR	2022/2025

	SE	SE objective	Scientific instrument	Start/Finish mission
	polarimetric side-view radar station with a synthesized aperture Kotel'nikov IRE RAS			
8	**«Napor-MiniRSA»** (SAR) Experimental development of compact SAR technology based on microstrip active antennas with phased array for solving problems of environmental management,environmental monitoring and emergency monitoring. RSC «Energia»	Design and manufacture of compact on-board SAR C-bandcomplex	SAR C-band (carrier frequency 5350 MHz)	2018/2019
9	**«Radiolokator»** Measurement of the dispersion of the sea-wave slopes, the height of significant waves and the velocity of the near-surface wind by the microwave radar with a fan antenna pattern. RNIIRS	Measuring the dispersion slopes of sea waves, the height of rough sea surface and wind speed in the channel near the nadir sounding	Pulse radar with AFAR - scanning radar microwave (wavelength ≈0,0222 m) with fan-shaped main antenna lobe (≈1^0x30^0).	2022/2025
10	**«Rakurs»** Multi-angle spectrometry of atmospheric internal gravity waves IPG	Testing of new methods for determining the characteristics of atmospheric internal gravity waves	Camera with a narrow-band interference filter (762 ± 5 nm); block of two photodetectors for limb shooting emissive layers in the atmospheric band (762 nm) and green line of atomic oxygen	2020/2022

	SE	SE objective	Scientific instrument	Start/Finish mission
			(557.7 nm) in the altitude range of 80-120 km	
11	**«Skatterometr-L»** The use of scatterometry methods for sea surface monitoring Kotel'nikov IRE RAS	Experimental verification of scatterometry methods in the decimeter range of electromagnetic waves to determine the velocity and direction of the driving wind, parameters of the ice and snow cover, soil moisture	Decimeter band scatterometer	2023/2025
12	**«Terminator»** Observation in the visible and near Infrared ranges of the spectrum of layered formations at the heights of the top mesosphere-the lower thermosphere in the vicinity of the solar terminator IPG	Study and restoration of the microstructure of mesospheric noctilucent clouds. The study of images obtained in the four spectrum bands	Microcameras of visible and near-IR bands	2018/2025
13	**«Uragan»** Experimental development of a ground-space system for monitoring and forecasting the development of natural and man-made disasters RSC «Energia»	Monitoring and recording the development of catastrophic phenomena from the ISS RS and developing criteria for the classification and interpretation of signs of catastrophic phenomena. Obtaining new experimental data with the help of RIVR during high-resolution spectral measurements of the underlying surfaces with spatial interpolation for scientific and practical use in the conditions of further development of the Earth remote sensing system Development of methods of monitoring the Earth's surface aboard the Russian segment of the international space station in conditions of real restrictions, due to the ballistic conditions of the ISS flight, the regime of work and rest of the crew, time crew resources, weather conditions and lighting conditions in the area, etc.	The high-resolution infrared radiometer (RIVR) has the limits of spectral ranges: from 3.5 to 4.1 μm; from 8 to 10 μm. Spatial resolution - 30m	2020/2024

	SE	SE objective	Scientific instrument	Start/Finish mission
14	**«Fon»** Monitoring of the optical characteristics of the atmosphere and the Earth's surface IKI RAS	Development of technical means, methods and mathematical support of technology for studying the spatial and temporal distribution of optical characteristics of the surface and atmosphere of the Earth, determining the correlation of these characteristics with the species (type) and the state of soil, plant, water, ice and snow cover of the Earth	Optoelectronic multispectral digital video radiometric system «Videoradiometr-300»	2022/2026