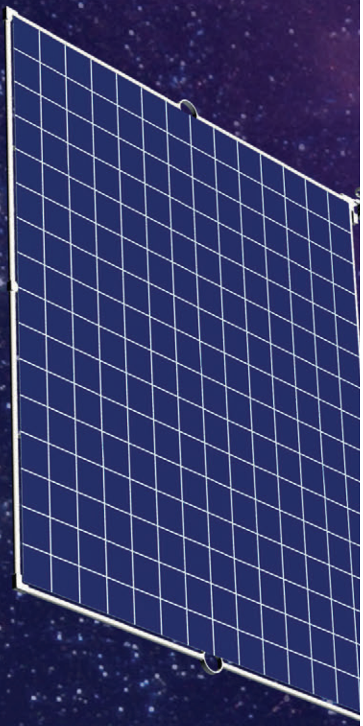

«Спектр-РГ»/Spektr-RG is the Russian project with the participation of Germany, carried out under the Agreement signed on 18 August 2009 between the Russian Federal Space Agency (Roscosmos) and the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR) during the MAKS-2009 International Aviation and Space Salon in Zhukovsky, Russia.

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Russian project with participation of Germany

Spektr-RG

ROSCOSMOS DLR MPE ИКИ

CONTEXT

The Spektr-RG all-sky survey will be a major step forward for X-ray astronomy, which celebrated its 50th anniversary a few years ago.

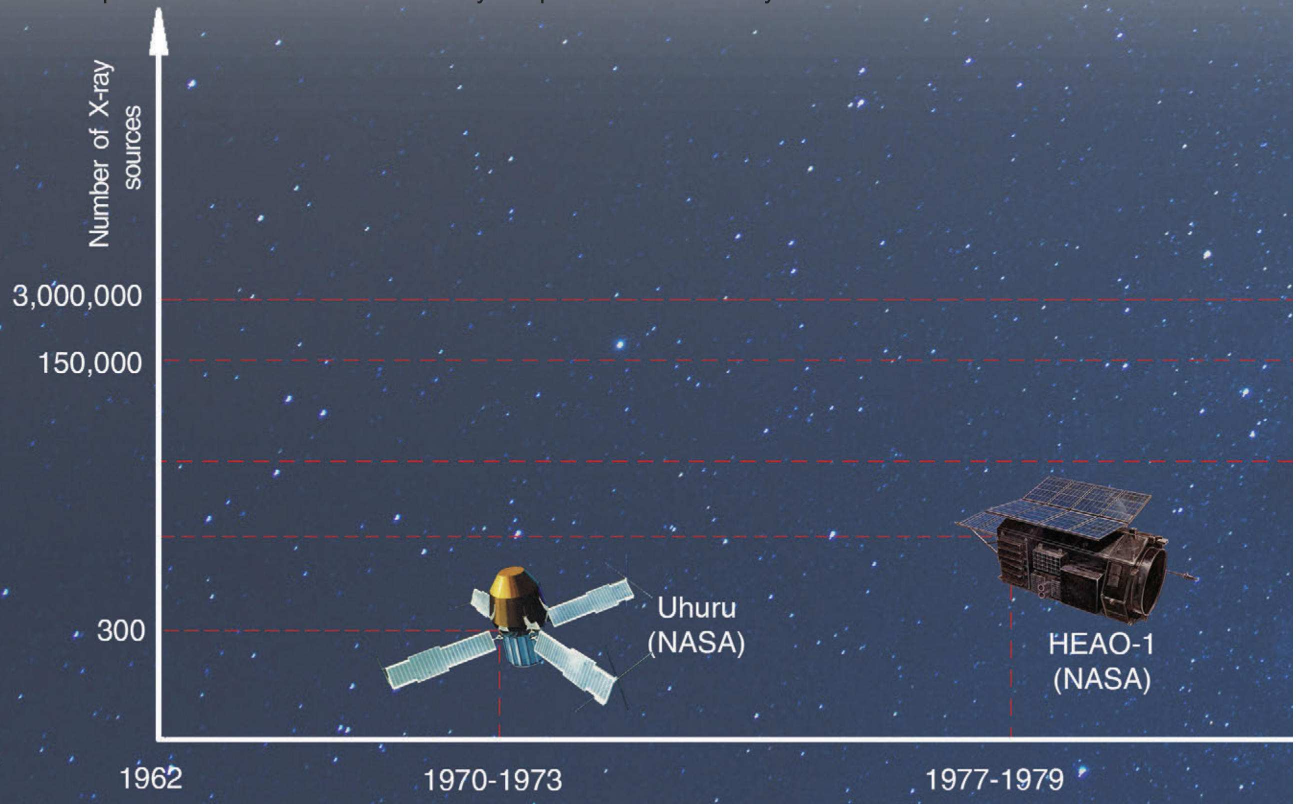
1962. Professor Riccardo Giacconi and his team are the first to identify X-ray emission originating from outside the Solar system (a neutron star dubbed Sco X-1). In 2002, he is awarded the Nobel Prize in Physics for this feat and the following discoveries of distant X-ray sources.

1970–1973. The first X-ray all-sky survey in the 2–20 keV energy band is carried out by the Uhuru space observatory (NASA). It discovers more than 300 X-ray sources in our Milky Way and beyond.

1977–1979. An even more sensitive survey is carried out by the HEAO-1 (NASA) space observatory at energies from 0.25 to 180 keV.

1989-1998. Over the initial four years of directed observations, the Granat astrophysical observatory (USSR) observes many galactic and extra-galactic X-ray sources with emphasis on the deep imaging of the Center of our Galaxy in the hard (40-150 keV) and soft (4-20 keV) X-ray ranges. Unique maps of the Galactic Center in X- and gamma-rays are created; black holes, neutron stars and the first microquasar are discovered. Then Granat carries out a sensitive all-sky survey in the 40 to 200 keV energy band.

1990–1999. In its first six months of operation the ROSAT space observatory (DLR, NASA) performs a deep all-sky survey in the soft X-ray band (0.1–2.4 keV). The observatory finds more than 150,000 X-ray sources of various kinds that are combined to produce the first detailed X-ray map of the whole sky.



SPEKTR-RG IN A NUTSHELL

Spektr-RG (SRG) is an astrophysical space observatory, aimed at studying our Universe in the X-ray band of the electromagnetic spectrum once it is in position at the Lagrange point L2 of the Sun-Earth system, 1.5 million kilometers away from Earth.

The Spektr-RG astrophysical space observatory is developed by the Russian side under the Federal Space Program of Russia, section on Fundamental Space Research, by order of the Russian Academy of Sciences with the participation of Germany.

ITS SCIENTIFIC TASKS

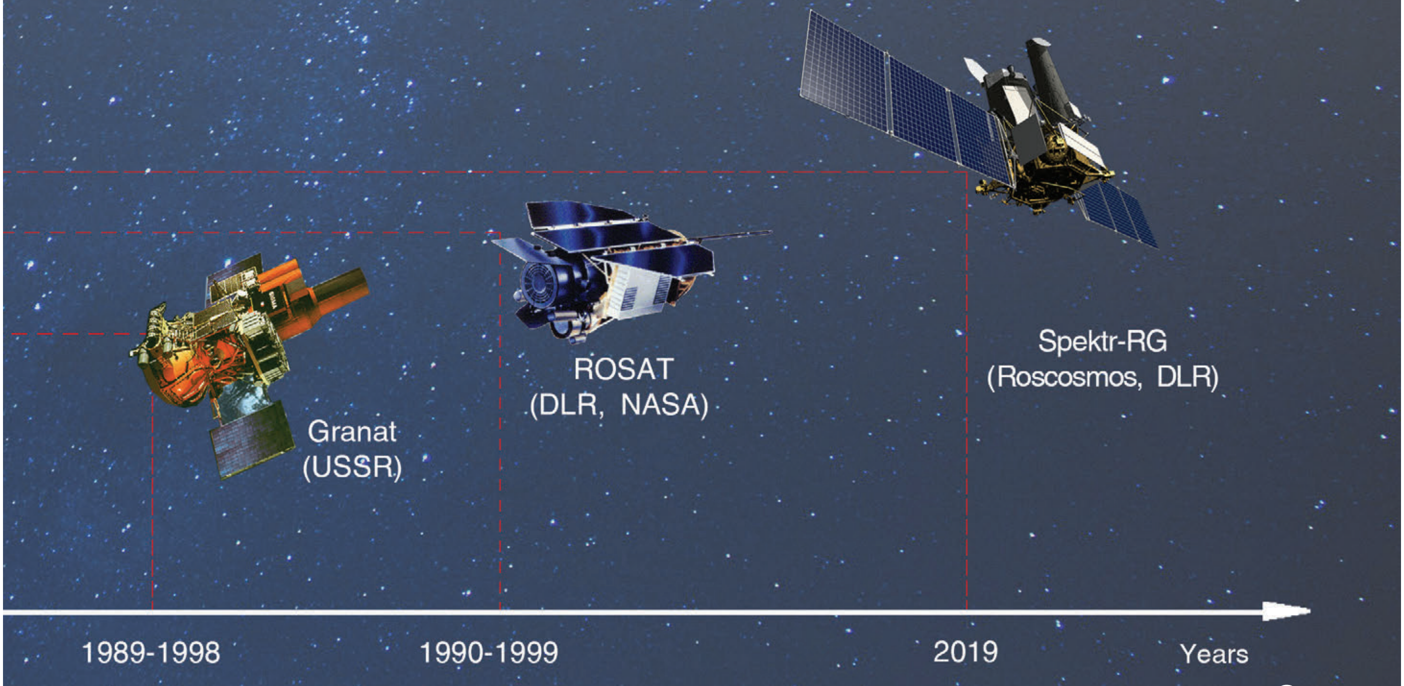
- to carry out an all-sky survey in the soft X-ray range (0.3–11 keV) with outstanding sensitivity;
- to perform a detailed study of selected astrophysical objects during subsequent observations in the harder energy range up to 30 keV.

ITS MISSION

The driving scientific goal of the Spektr-RG observatory is to map all massive structures in the observable Universe in X-rays. This map will be essential to solve the core questions of modern cosmology: How do dark energy and dark matter affect formation of the large-scale structure of the Universe? What is cosmological evolution of supermassive black holes?

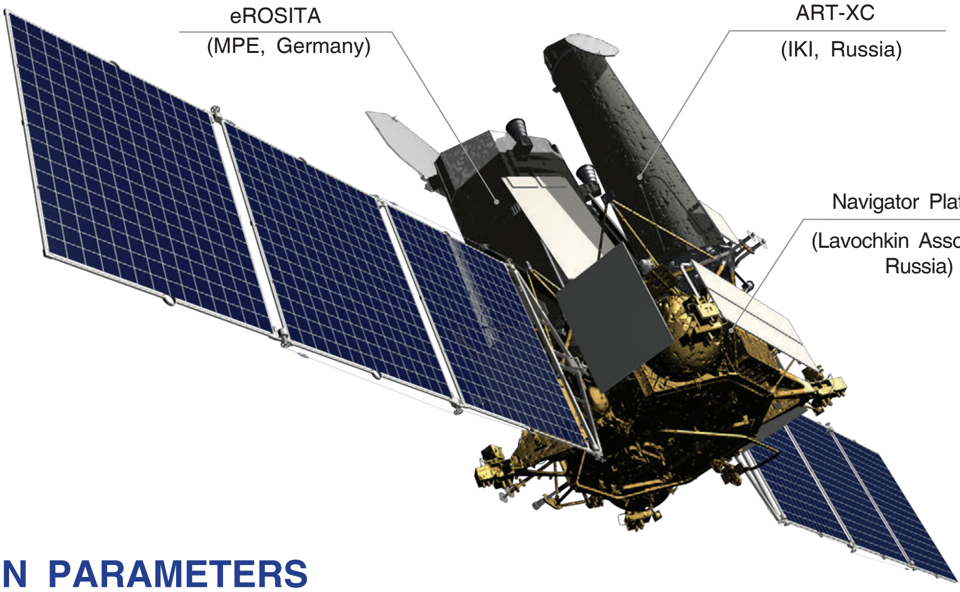
EXPECTED RESULTS

Spektr-RG is expected to find about 100,000 massive clusters of galaxies during the four-year survey mode, which means literally all such objects in the observable Universe.
Furthermore, it will detect around three million supermassive black holes in active galactic nuclei (AGN), along with hundreds of thousands of stars with active coronae and accreting white dwarfs, tens of thousands of galaxies with active star formation. There might even be other objects of unknown nature. Spektr-RG will also study the hot interstellar and intergalactic medium, which is a source of bright X-ray emission.



SPACECRAFT

Spektr-RG carries two unique instruments, the eROSITA and ART-XC X-ray telescopes. Both exploit the principles of grazing incidence imaging X-ray optics. To be reflected, X-ray photons must hit the mirror surface at a very small angle. Hence, X-ray mirrors are very oblong and tube-like. To increase the number of photons registered, several mirrors of ever increasing diameters are nested one into the other. Thus, one module consists of several mirror shells, and both telescopes consist of 7 modules each, with high-performance X-ray detectors placed in each focal point.



MAIN PARAMETERS

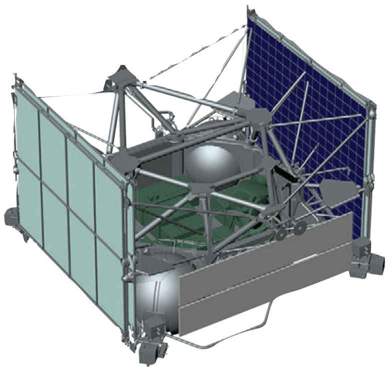
Spacecraft wet mass	2712.5 kg
Scientific payload mass	1210 kg
Power	1805 W
RF line band	X-band
Scientific data transmission rate	512 Kbit/s
Expected lifetime	6.5 yrs

NAVIGATOR SPACE PLATFORM

adapted for the tasks of the project

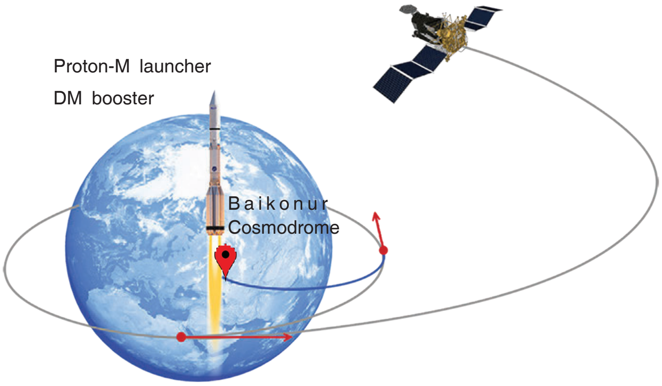
Navigator platform is developed as the baseline module for key systems adaptable for various payloads and orbits.

Navigator is a flight qualified platform. The Spektr-R highly elliptical spacecraft (launched in 2011) and two hydrometeorological Elektro-L geostationary satellites (launched in 2011, 2015) were built on this platform.



LAUNCH, CRUISE, OPERATION

INJECTION SCENARIO



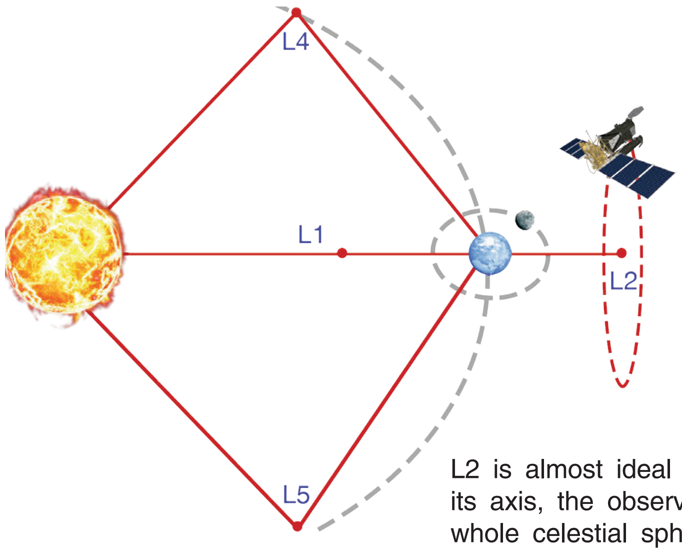
The Proton-M launcher (Khrunichev Space Center, Russia) equipped with an advanced control system has high performance and ecological characteristics. More than 100 launches of Proton-M have been performed since its inaugural flight.

Usage of the DM upper stage (RSC Energia, Russia) with a sustainer engine of multiple switch-on enables implementation of various spacecraft injection scenarios and increasing of launch reliability.

CRUISE AND OPERATION SCHEDULE

- ~3 months after launch — cruise to L2, positioning, calibration and testing, test observations;
- 4 years — all-sky survey in 0.3–11 keV energy band;
- 2.5 years — observations of selected objects and regions in the harder X-ray range up to 30 keV in a 3-axis stabilization mode.

OPERATION ORBIT



Halo orbit around Sun-Earth L2 outer Lagrange point, about 1.5 million kilometers from Earth

Orbital period around L2 is about 6 months

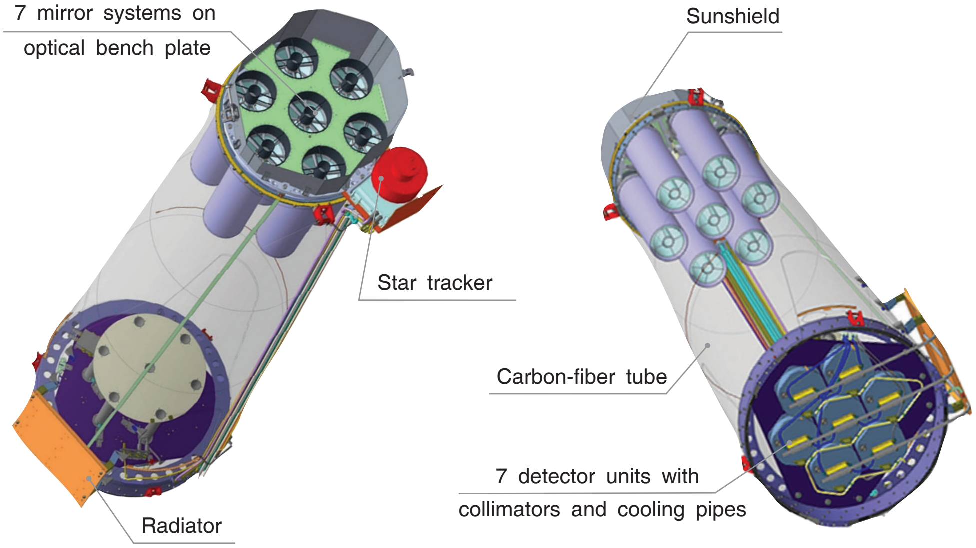
Maximum distance from ecliptic plane is 400,000 km

L2 is almost ideal for surveys. Spinning around its axis, the observatory will be able to map the whole celestial sphere in half a year. As the axis is pointed approximately to both Sun and Earth, the Sun itself does not enter the field of view. This means that eight all-sky surveys will be carried out in the first four years of operation. The technical challenge is to keep the spacecraft in orbit; therefore, periodical correcting maneuvers are envisaged.

ART-XC TELESCOPE (RUSSIA)*

The telescope is built by the Space Research Institute of the Russian Academy of Sciences (IKI) and Russian Federal Nuclear Center.
Principal Investigator — Dr. Mikhail Pavlinsky.

ART-XC extends the operational range of the eROSITA telescope to higher energies up to 30 keV. Energy ranges of the telescopes overlap giving advantages in their calibrations and increasing reliability of scientific results.



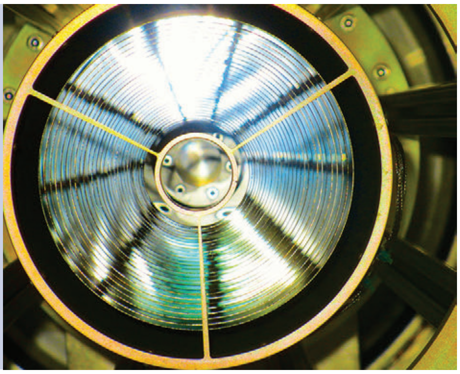
MAIN PARAMETERS

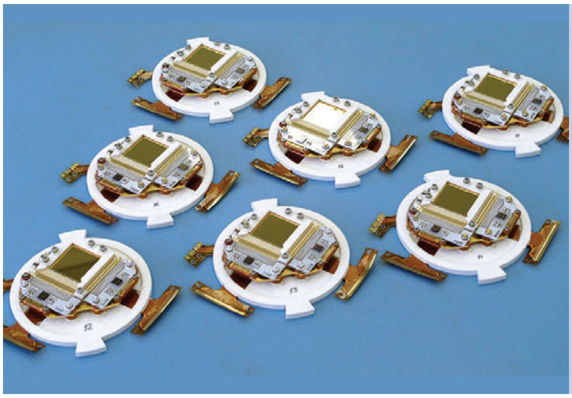
Energy range	5–30 keV
Angular resolution	45 arc seconds
Field of view	0.3 sq.degrees
Mass	350 kg
Energy consumption	300 W
Number of mirror modules	7
Number of mirror shells per each module	28
Mirror shell length	580 mm
Mirror shell diameters	49-145 mm
Focal length	2700 mm
Mirror material	Nickel/Cobalt
Mirror coating	Iridium
Detectors	DSSD, CdTe
Detector dimensions	30 x 30 mm
Detector operating temperature	-20 ^{0}C

*ART-XC is short for Astronomical Roentgen Telescope - X-ray Concentrator.

Mirror systems for the flight models of the telescope were built at NASA Marshall Space Flight Center (USA).

Along with these, mirror systems were made at the Russian Federal Nuclear Center — All-Russian Scientific Research Institute for Experimental Physics, which were installed in the test model of the telescope and used during endurance tests.





Semiconductor CdTe detectors, which are placed in focal points of each mirror system, were designed and made at IKI High-Energy Astrophysics department. One detector set includes 7 detector modules, 30 x 30 x 1 mm each.

GOALS

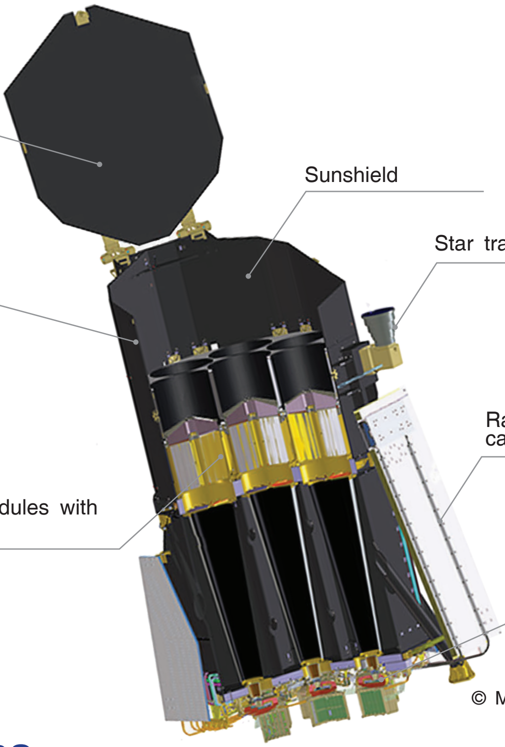
- To map the sky with unprecedented depth in 5–11 keV energy range and ecliptic poles in 5–30 keV. At these energies the interstellar medium has relatively small absorption effect upon the radiation fluxes in comparison with lower energies. Combined with high angular resolution, this property is essential to register and localize the sources of hard X-ray emission in the sky. In particular, more than one thousand active galactic nuclei will be discovered, and, among them, several thousand growing supermassive black holes, hidden from us by thick shells of dust and gas, surrounding the accretion disc;

- To get for the first time a large sample of accreting white dwarfs and measure their masses and other parameters;

- To register transient X-ray sources and look for the sources of previously unknown types.

eROSITA TELESCOPE (GERMANY) *

Leading institute — Max Planck Institute for Extraterrestrial Physics (MPE).
Principal Investigator — Dr. Peter Predehl.

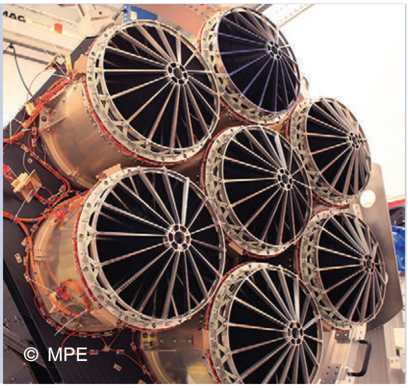


MAIN PARAMETERS

Energy range	0.3–11 keV
Angular resolution	18 arc seconds
Field of view	0.81 sq. degrees
Mass	815 kg
Energy consumption	405 W
Number of mirror modules	7
Number of mirror shells per each module	54
Mirror shell length	300 mm
Mirror shell diameters	76–358 mm
Focal length	1600 mm
Mirror material	nickel
Mirror coating	gold
Detectors	PNCCD, Si
Detector dimensions, mm	28.8 x 28.8
Detector operating temperature	-95 ^{0}C

*eROSITA – is short for extended ROentgen Survey with an Imaging Telescope Array.

The eROSITA telescope is based on an optical systems with seven “eyes” for X-rays and seven cameras placed in their respective focal planes. The X-ray optics consists of gold-coated, tubular mirrors, where 54 nested mirrors are forming one module.



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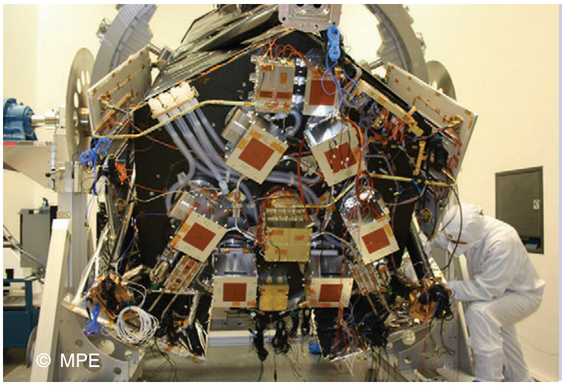
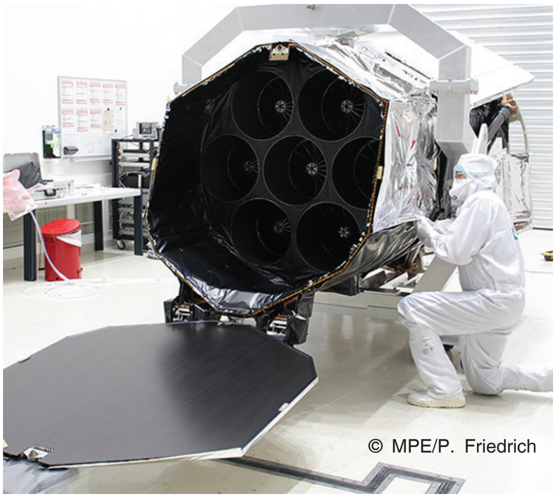


© MPE

Developed and built at MPE, the cameras contain special X-ray CCDs manufactured from highly pure silicon. For maximum performance, these cameras have to be cooled to -95°C using a complex passive cooling system with heat pipes and radiators.

GOALS

- To make an all-sky survey in 0.3–11 keV energy band with unprecedented spectral and angular resolution, which are essential for further studies of dark matter and other objects in the Universe;
- To detect systematically all obscured accreting Black Holes in nearby galaxies and many (up to three million) new, distant active galactic nuclei;
- To detect the hot intergalactic medium of 50–100,000 galaxy clusters and groups and hot gas in filaments between the clusters to map out the large scale structure of the Universe for the study of cosmic structure evolution;
- To study in detail the physics of galactic X-ray source populations, like pre-main sequence stars, supernova remnants and X-ray binaries.



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SCIENCE

THE UNIVERSE for physicists is a large lab, where they can probe the matter under conditions, which cannot be attained on Earth. In particular, there are temperatures of billions of degrees, great pressure, immense magnetic and gravitational fields. To a certain extent, we can witness and study these processes, but not all of the signals from distant objects can reach the Earth's surface freely.

X-ray emission (0.1–100 keV) is of special importance, as it accompanies the most energetic events in the Universe: supernovae, accretion to neutron stars and black holes, and many more. However, the terrestrial atmosphere is opaque for X-rays, so the only way to study it is to put the probes outside — in space.

Hot gas in clusters of galaxies also emits X-ray photons, its distribution traces the distribution of matter in the Universe. An all-sky survey, or "census", of clusters of galaxies, which is expected to be finalized during the Spektr-RG project, will shed new light on how the Universe is built.

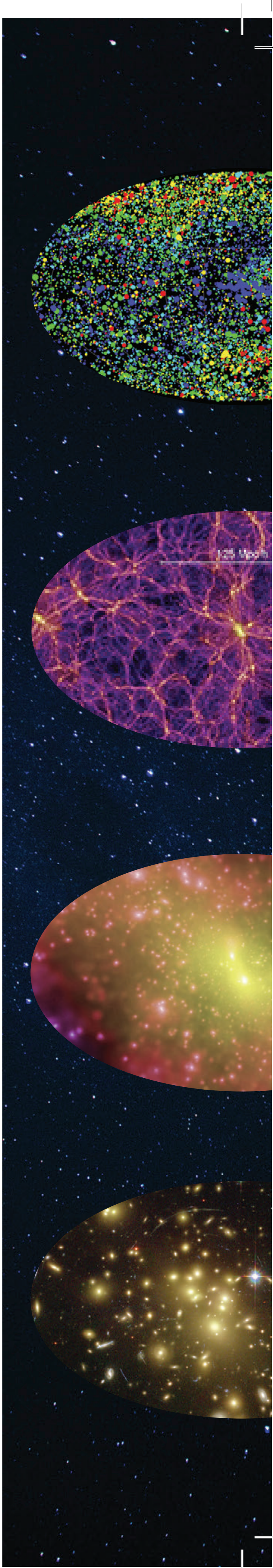
CLUSTERS OF GALAXIES

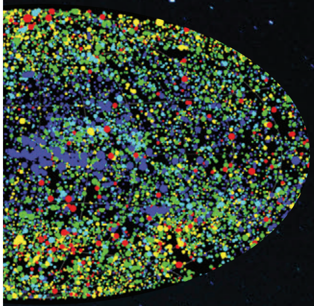
Clusters of galaxies are the most massive objects in the Universe that are pulled together by gravitation. Such a cluster can be considered as a single object, because its galaxies and hot intergalactic gas (with temperatures up to tens of millions of degrees) are located in a common gravitational well, whose source is dark matter. Large clusters of galaxies can contain from the hundreds to thousands of galaxies; the total mass of a cluster can reach up to 1000 trillion solar masses.

Clusters of galaxies form the **large-scale structure** of the Universe, which resembles a spiders's web. At it nodes are the clusters of galaxies and intergalactic gas connected by filaments and separated by so-called voids with almost no matter inside.

Dark matter (or, more precisely, hidden mass) is considered to be at the origin of clusters of galaxies. This is an exotic kind of matter, which does not emit electromagnetic light and interacts with more common (baryonic) matter only gravitationally. The clumps of dark matter formed gravitational wells, pulling common matter into it, and that is how stars (and their planetary systems), galaxies, groups and clusters of galaxies started to grow in the early Universe. The most massive clusters of galaxies are still being formed even now.

Spektr-RG shall register all the most massive clusters of galaxies in the observable Universe, i.e. throughout the space available for observations. This means that we will study not only the present, but also the past of the Universe, since the farthest clusters of galaxies have an age comparable to that of the Universe itself. To trace their evolution through time is to follow the history of everything.





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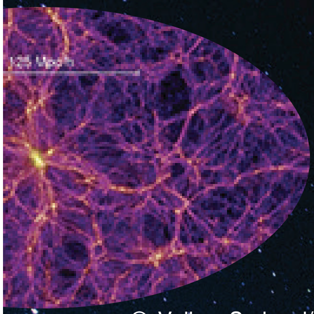

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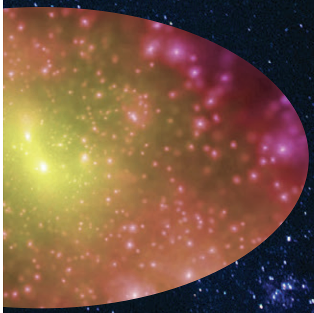
Max Planck Institute
For Astrophysics/
SPL et al, 2005.

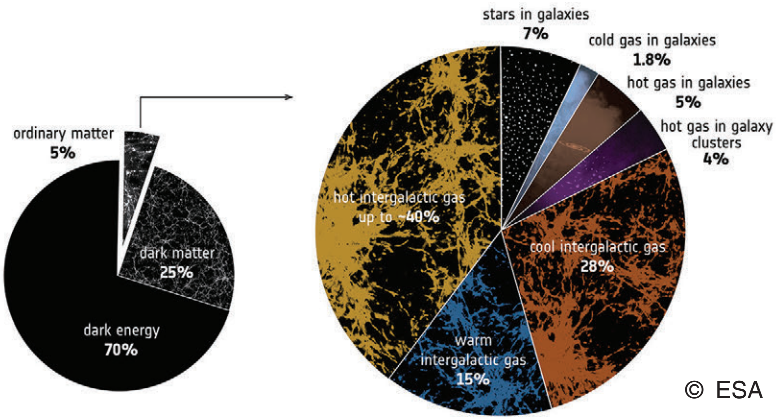


COSMOLOGY MATTERS

Cosmology is a branch of astronomy concerned with the studies of the origin and evolution of the Universe. According to the currently accepted model in cosmology, our Universe is made up of 25% of dark matter, 70% dark energy, and 5% ordinary matter.

Along with dark matter, another major constituent of the Universe is **dark energy**, no less mysterious and exotic. Its effect can be seen in the accelerating expansion of the Universe. Dark energy accounts for about 70% of the total mass-energy balance in the Universe, but it reveals itself only at very large scales. If we map all clusters of galaxies in space, we may gauge the impact of "dark energy" and, possibly, come closer to answering the question about its nature.

Composition of the Universe



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ACTIVE GALACTIC NUCLEI

Many galaxies host **supermassive black holes** at their cores. The masses of these objects reach millions and even billions of solar masses, and they actively accrete, or gather, surrounding matter. During this process, they actively radiate energy (in particular X-rays) and emit relativistic jets of matter.

Spektr-RG should discover about three million active galactic nuclei at various distances, giving us an indication on when these exotic objects first appear in the Universe and how fast they grow.

GROUND SUPPORT

Spektr-RG will observe many X-ray sources. To measure the distances to them and reveal their nature, observations in other energy bands (primarily optical) are essential. The Spektr-RG project includes a large collaboration of ground-based observatories, which provide follow-up observations for its space observations.

From the Russian side, the main ones are:

1) BTA-6, Special Astrophysical Observatory of the Russian Academy of Science, 6 meter

2) Caucasus Mountain Observatory, Sternberg Astronomical Institute, Lomonosov Moscow State University, 2.5 meter

3) RTT-150 Russian-Turkish Telescope, located in Turkey, jointly operated by Kazan Federal University, IKI, and Tubitak National Observatory TUG (Turkey), 1.5 meter

4) AZT-33IK and AZT-33VM, Sayan Solar Observatory, Institute of Solar-Terrestrial Physics, Russian Academy of Sciences, Siberian Branch, 1.6 meter each.

From the German side, there are:

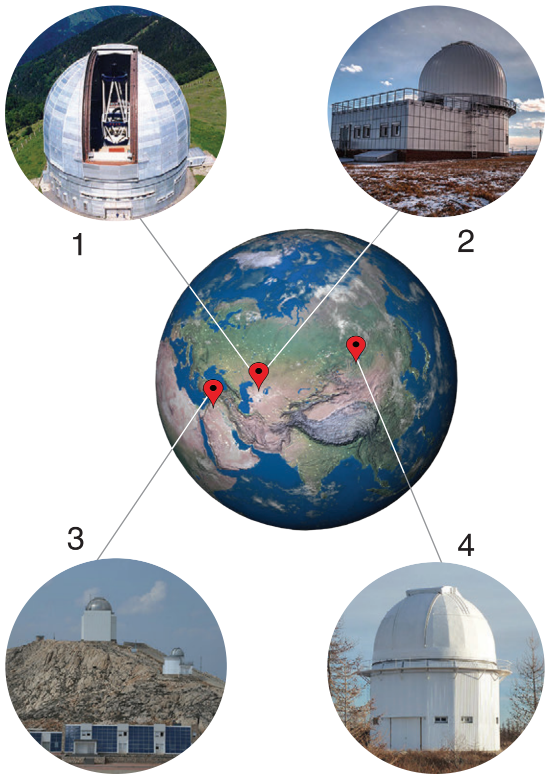
1) SDSS-V: all-sky optical spectroscopic survey programme with 2.5 meter wide-field telescopes at Apache Point Observatory (APO, New Mexico) and Las Campanas Observatory (LCO, Chile)

2) DECam: Wide-field optical imaging from 4 meter Blanco telescope at the Cerro-Tololo Inter-American Observatory in Chile

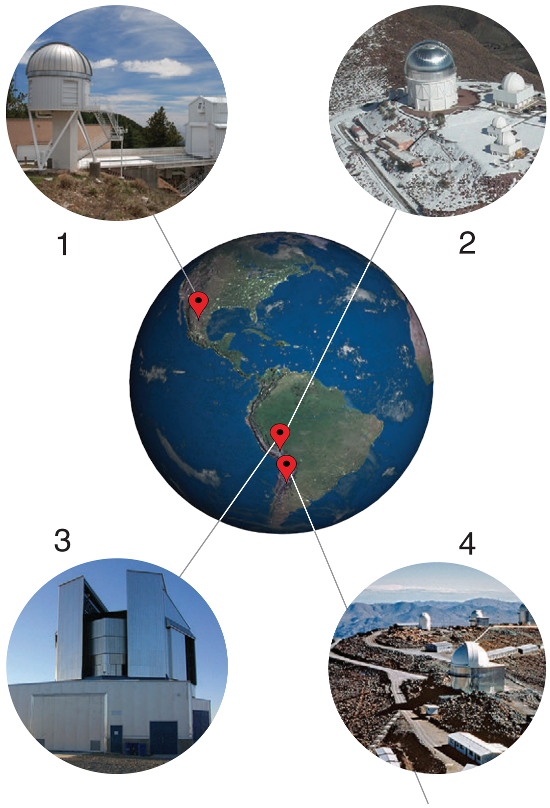
3) 4MOST: Wide-field optical spectroscopic follow-up with ESO/VISTA 4 meter telescope at Paranal, Chile

4) GROND: Optical/NIR simultaneous imaging at the ESO 2.2 meter telescope at La Silla, Chile.

From the Russian side



From the German side



INTERNATIONAL COLLABORATION

ROSCOSMOS State Corporation	DLR German Space Administration
Lavochkin Association	Max Planck Institute for Extraterrestrial Physics (MPE)
Space Research Institute (IKI)	Institute for Astronomy and Astrophysics (IAAT), University of Tuebingen
Russian Federal Nuclear Center — All-Russian Research Institute of Experimental Physics	Leibniz Institute for Astrophysics Potsdam (AIP) Hamburg Observatory, Hamburg University
NASA Marshall Space Flight Center (MSFC)	Dr. Remeis Observatory Bamberg, University Erlangen-Nuremberg

Leading organizations:

- from the Russian side for scientific payload: IKI
- from the Russian side for space and ground segment (except for scientific payload): Lavochkin Association
- from the German side for eROSITA telescope: MPE

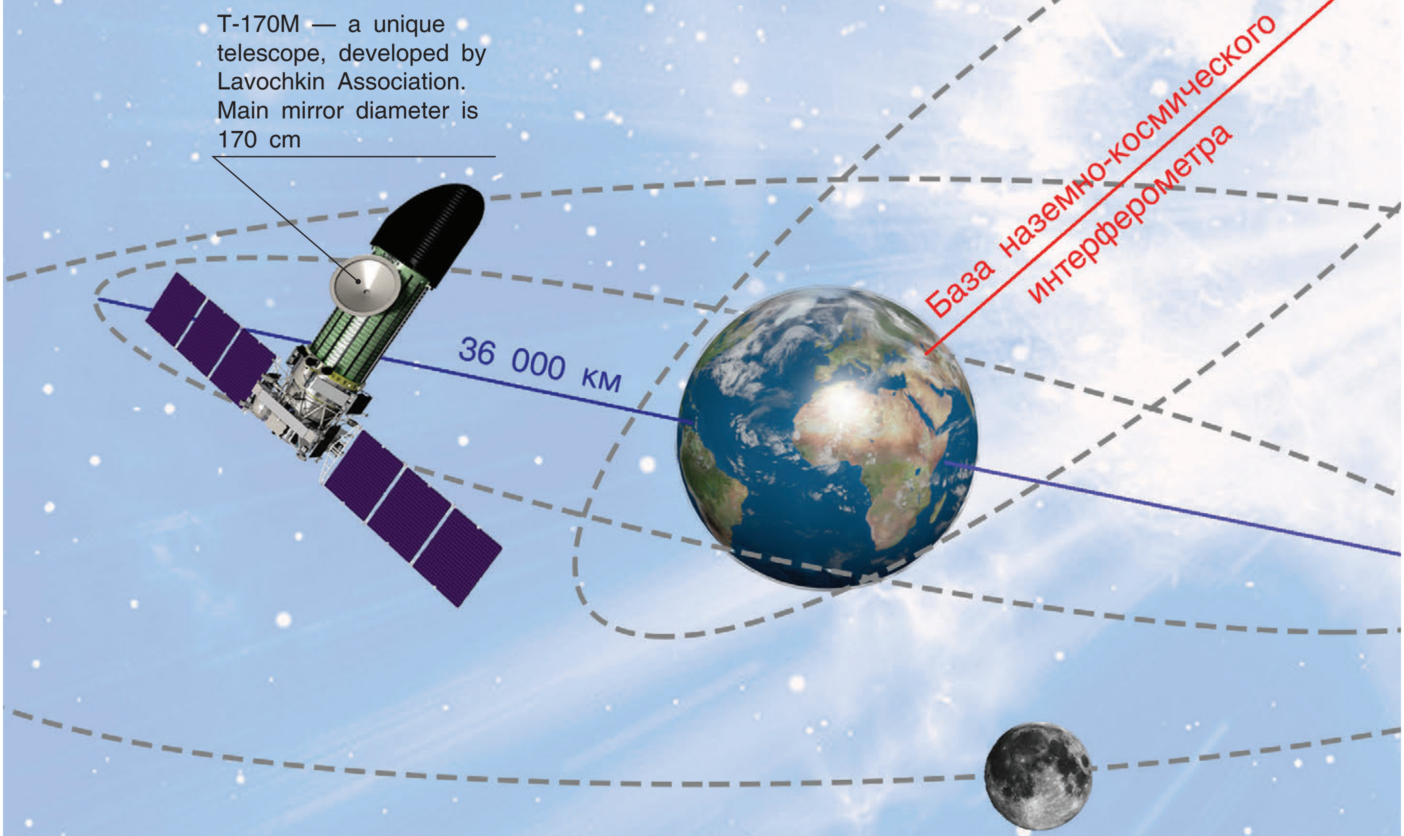
From the Russian side, Mission Scientific Leader: Acad. Rashid Sunyaev
From the German side, eROSITA telescope Principal Investigator: Dr. Peter Predehl

ALL SPEKTR OBSERVATORIES TILL 2025

SPEKTR-UF

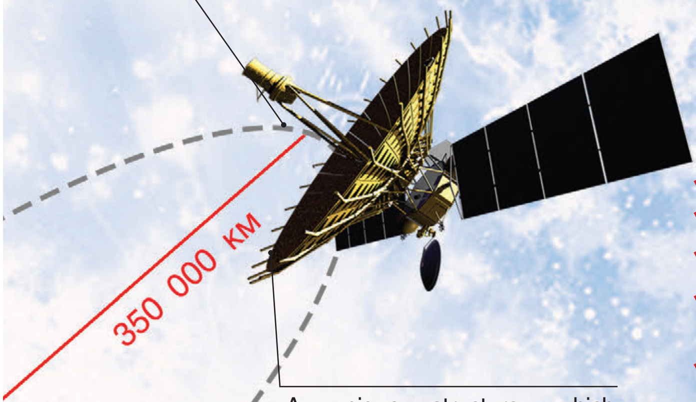
Launch in 2025

Space observatory to study the Universe in the ultraviolet (UV) and visible range.



The space observatories of the Spektr series are aimed at studying the Universe in all ranges of electromagnetic spectrum to obtain unique astrophysical data and create the most complete picture of the Universe.

The largest space-borne radio telescope with a 10 meter diameter antenna



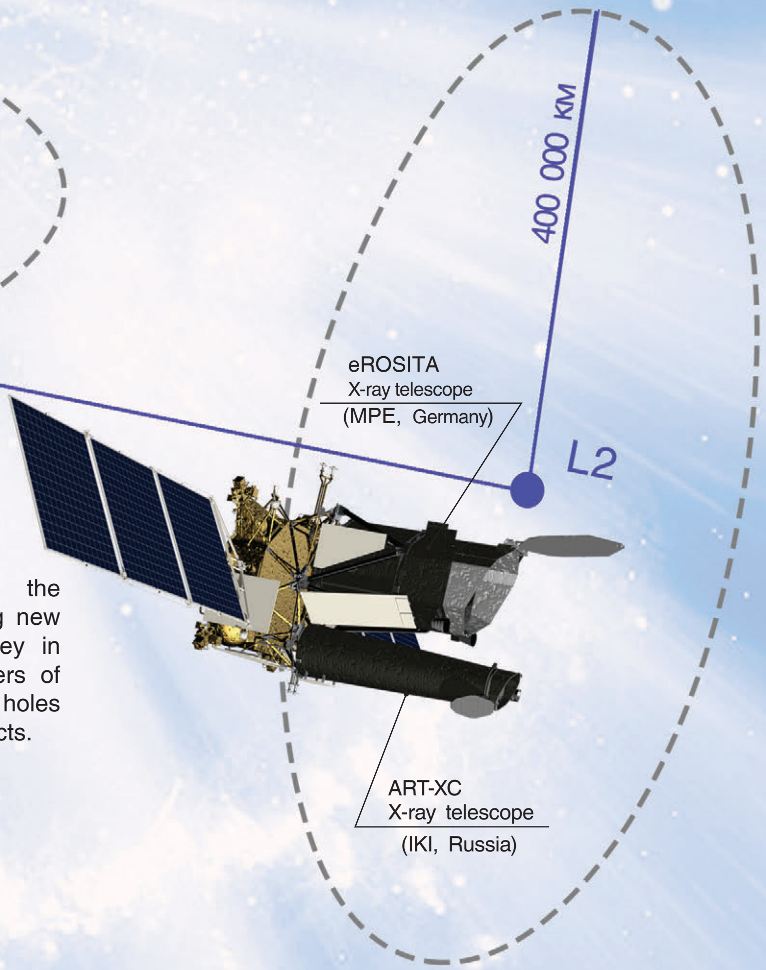
A unique structure, which includes 27 opening “petals” and the central 3 meter mirror was developed by Lavochkin Association

SPEKTR-R

Launched on July 18, 2011

Studies the Universe in radio band with unprecedented angular resolution (the record is 8 microarcsecond).

- ✓ 4 Pbyte of stored data
- ✓ 250 objects studies
- ✓ > 4,000 observational sessions
- ✓ 240 scientists from 23 countries participated in observations
- ✓ > 60 radio telescopes in the project



SPEKTR-RG

Launch in 2019

Astrophysical observatory to study the Universe in the X-ray band performing new 20 times more sensitive all-sky survey in X-rays to detect about 100,000 clusters of galaxies, 3 million supermassive black holes in AGNs and thousands of other objects.