Status of the Astronomical Rotengen Telescope - X-ray Concentrator (ART-XC)
Spectrum-Roentgen-Gamma (SRG)

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. SRG is a joint observatory consisting of two telescopes: the German-made eROSITA and the Russian-made Astronomical Roentgen Telescope - X-ray Concentrator (ART-XC); ART-XC is built around MSFC designed & fabricated grazing incidence X-ray optics.

EXPECTED RESULTS
SRG will survey the sky every 6 months for the first 4 years of a 7 year mission and will operate in pointed mode the last 3 years. Over the mission it is expected to find about 100,000 massive clusters of galaxies, 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. SRG will also study the hot interstellar and intergalactic medium, which is a source of bright X-ray emission.
ART-XC Overview

Project Summary: Manufacture grazing angle optical assemblies supporting Russian Space Research Institute of Russian Academy of Sciences (IKI) ART-XC telescope

Project Description:
- Deliver 1 engineering unit, 4 flight units and 1 flight spare to IKI. Manufacture 28 mandrels, electroform shells, Iridium coated shells, assemble, perform thermal, acoustic, shock, vibration and x-ray test on engineering unit and acceptance vibration test and x-ray calibration on flight units.
- Deliver 3 additional flight units to IKI using existing 28 mandrels, manufacture 84 additional Iridium coated shells, assemble, perform acceptance level vibration and x-ray calibration.

MSFC Role:
Provide project management, project scientists, optical design, shell production, module assembly and environmental and x-ray testing
## ART-XC Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>5–30 keV (.248 – .041 nm)</td>
</tr>
<tr>
<td>Field of view</td>
<td>0.3 sq. degrees</td>
</tr>
<tr>
<td>Mass</td>
<td>350 kg</td>
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<tr>
<td>Power</td>
<td>300 W</td>
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<tr>
<td>Number of mirror modules</td>
<td>7 + 1 flight spare</td>
</tr>
<tr>
<td>Number of shells per module</td>
<td>28</td>
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<tr>
<td>Mirror shell length</td>
<td>580 mm</td>
</tr>
<tr>
<td>Mirror shell diameters</td>
<td>49-145 mm</td>
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<tr>
<td>Mirror shell thickness</td>
<td>250 μm to 350 μm</td>
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<tr>
<td>Focal length</td>
<td>2700 mm</td>
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<tr>
<td>Mirror material</td>
<td>Nickel/Cobalt</td>
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<tr>
<td>Mirror coating</td>
<td>Iridium - 10 nm thick</td>
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<tr>
<td>Optics angular resolution</td>
<td>30 arc seconds</td>
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<tr>
<td>Detectors</td>
<td>DSSD, CdTe</td>
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<tr>
<td>Detector angular resolution</td>
<td>45 arc seconds</td>
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<tr>
<td>Detector dimensions</td>
<td>30 x 30 mm</td>
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</tbody>
</table>
Replicated Optics Manufacturing Process

1. CNC machine, mandrel formation from Al Bar
2. Chemical clean and activation & Electroless Nickel (EN) plate
3. Precision turn to sub-micron figure accuracy
4. Polish and superpolish to 3-4 Å finish
5. Metrology – repeat Step 4 until surface finish met
6. Ultrasonic clean & passivation to remove surface contaminants
7. Electroform nickel shell onto mandrel
8. Separate optic from mandrel – reuse mandrel for next shell
9. Test module
8. Align shells into module
Currently contracted out
ART-XC Hardware

Mounting “Spider”

28 Nested Iridium Coated Nickel/Cobalt Shells

Thermal Housing

Optical Baffle

Mounting “Comb”
ART-XC Alignment

4 custom alignment stations

Alignment of shells to spider

Final mirror module assembly in lifting fixture – mirrors are 580mm long, but supported at one end
Guide Tube
101 m long
1.3 m diameter
0.65 m above floor of 3m x 12 m chamber

Test Energy Ranges
0.5 – 5 kV Manson source vacuum on Beam Line
10 keV sources are at vacuum inside Beam Line
125 kV & 225 kV sources in air through Beryllium Windows
Russian Activities

Detector development
Integration of telescope
Integration to spacecraft bus
Assembly on Proton-M

Launch - 14 July 2019
The first images obtained from the ART-XC telescope. The picture shows the bright X-ray pulsar Centaurus X-3 (Cen X-3). The deviation of the optical axes of the seven mirror systems with respect to boresight of the spacecraft is 11.33 arcmin. In the near future, all seven modules of the ART-XC telescope will be aligned with the spacecraft. Temporal analysis of the data showed a steady periodic signal with a period of 4.8 seconds. Cen X-3 is a system composed of a neutron star orbiting a massive, O-type supergiant star, located at a distance of ~18,600 light years.
After calibration, ART-XC began a performance verification program. In the first scanning observation of the bulge (central “bulge”) of the Milky Way galaxy, a new X-ray source SRGA J174956-34086 was discovered. On the left is the ART-XC data (4-11 keV) image, on the right - is the Swift / XRT image (0.3-10 keV). In soft X-rays, SRGA J174956-34086 turned out to be dimmer, which is usually found when sources are located behind clouds of interstellar gas and dust.

On August 13, 2019 the Spektr-RG space observatory sent its first astronomic “telegram” while observing the supermassive black hole (4 million times heavier than the Sun) Sagittarius A* in the center of the Milky Way.
A 5-16 keV ART-XC image of the center of the Milky Way is shown on the left. The image was accumulated during a 80 minute exposure. The right panel shows a corresponding NuSTAR mosaic of the same field obtained with a 40-hour exposure. Despite the short exposure, ART-XC clearly detects all the identifiable objects in the field including molecular cloud complexes, the Arches star cluster, several bright X-ray binaries, and Sgr A* itself.
MSFC has been pursuing electroform nickel replicated x-ray optics since the late 1990’s. Using balloon and sounding rocket flights to develop the technology and improve the figure and surface roughness of the shells, ART-XC will advance the technology to TRL 9.