Status and Calibration of the eROSITA X-ray Telescope

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on behalf of the eROSITA Team
IACHEC, Lake Arrowhead, USA, 29-Mar-2017
Spektr-Rentgen-Gamma (SRG)

Launch March 2018 from Baikonur

Proton Rocket + Block DM upperstage
Former: Zenith + Fregat

IACHEC, Lake Arrowhead, USA, March 29, 2017
Spektr-RG Mission Profile

Orbit around L2

Permanent Rotation of S/C, ~ 4 hours / revolution

4 years all-sky survey
3 years pointed observations
Expected Telescope Survey Effective Area

Effective areas of the three filter combinations for one eROSITA camera, composed of the expected effective area of one mirror assembly (averaged over the FoV), the filter transmissions, and the CCD quantum efficiency. All values are preliminary.

IACHEC, Lake Arrowhead, USA, March 29, 2017
# FM Hardware Status ➔ Complete

<table>
<thead>
<tr>
<th></th>
<th>March 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror Modules (8)</td>
<td>ready</td>
</tr>
<tr>
<td>X-ray Baffles (8)</td>
<td>ready</td>
</tr>
<tr>
<td>Electron Deflectors (8)</td>
<td>ready</td>
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<tr>
<td>Filterwheels (8)</td>
<td>ready</td>
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<tr>
<td>Camera Mechanics (8)</td>
<td>ready</td>
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<tr>
<td>Electronics Boxes (10 FM)</td>
<td>ready</td>
</tr>
<tr>
<td>Electronics Heatpipes (9)</td>
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</tr>
<tr>
<td>Harness</td>
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<tr>
<td>MLI</td>
<td>ready</td>
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<tr>
<td>Heatpipe System Camera</td>
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</tr>
<tr>
<td>Telescope Structure</td>
<td>ready</td>
</tr>
<tr>
<td>Radiators (4)</td>
<td>ready</td>
</tr>
<tr>
<td>CCD-Modules (11)</td>
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</tr>
<tr>
<td>Electronics</td>
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</tbody>
</table>

IACHEC, Lake Arrowhead, USA, March 29, 2017
Completed Telescope Cameras

IACHEC, Lake Arrowhead, USA, March 29, 2017
Completed Telescope: Mirrors

IACHEC, Lake Arrowhead, USA, March 29, 2017
Completed Telescope: PANTER Final Test

IACHEC, Lake Arrowhead, USA, March 29, 2017
Completed Telescope: PANTER Final Test
eROSITA Departure from PANTER

Dec. 5th 2017
Transport to Moscow
eROSITA at Lavochkin, Moscow

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Qualification Tests & Calibration

Vibration: MPE Shaker, IABG
Acoustic Noise: IABG
EMC: MPE, IABG
Thermal Vacuum: MPE: TVK2,4,5, PUMA, PANTER, IABG
Calibration: MPE: GEPARD, PUMA, PANTER
eROSITA Mirror Tests at the PANTER test Facility

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Calibrating the eROSITA X-ray Optics at PANTER

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Vacuum: \( p = 2 \times 10^{-7} \text{ mbar} \)
StirlingCooler: \( T < -120^\circ C \)
2nd cooler for electronics

Multitarget X-ray Source
Double Filterwheel
charact. lines 0.3keV – 10keV

eROSITA FM camera in PUMA
The eROSITA Cameras

Graded Shield

Contamination Shield

Filter Wheel with Calibration Source

Electronic Box

pnCCD
The eROSITA Cameras

- 7 framestore pn CCDs developed at MPE
- 50 ms frame time
- Sensitive in the 0.2-10 keV
- 5 CCDs with on chip Al-filter 2 without
- Filterwheel with Al, PI filters and Fe55 calibration source
- Energy Resolution 50eV@0.3keV 157eV@6.4keV
FM Camera Calibration

- Spectral resolution at all 9 measured energies well within specification
- Extremely good uniformity
- Only weak dependence on temperature of CCD and electronics (unlike XMM-EPIC!)

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Onboard Fe 55 Calibration Source

Al Kα  Ti Kα  Mn Kα

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Summary of detector calibration measurements

- At least 1 energies from C-K to Ge-K have to be measured

- ~30 million events per energy with
  - no pile-up
  - enough first singles (~10/pixel)
  - low continuum

- In total about one week of measurements per camera is needed at PUMA
The eROSITA Mirror Modules

Stray-light as driver for baffle design

- Optical stray-light
  - Sun shield
  - Baffle (against Earth radiation)
  - Mirror backsides
  - Filter

- X-ray stray-light
  - Baffle (against off-axis single reflections)
  - Mirror backsides
eROSITA Mirror Calibration

Each of the 8 Mirror Modules (7 FM and 1 spare) will have gone through the following procedure:

- an X-ray acceptance test
  - HEW and effective area
- Integration of the baffle unit
- X-ray test after baffle integration
  - HEW and effective area
- Environmental tests (thermal cycling and vibration)
- Final calibration tests to measure the:
  - PSF on-axis / off-axis in the energy range 0.28 – 8.04 keV
  - Effective area in the energy range 0.28 – 8.04 keV
  - Contribution of scattering
  - Focal length measurement in X-rays and physically

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Mirror Assembly in PANTER

“IACHEC, Lake Arrowhead, USA, March 29, 2017”
FM Mirror Calibration Overview

Calibration Activities:

- Alignment (pitch, yaw)
  - Optical
  - X-ray (Al-K)
- Focus search (Al-K)
- Deep in-focus, on axis (HEW)
- Focal plane mapping (C-K .. Cu-K)
  - PSF on-/off-axis
  - Eff. Area on-/off-axis
  - Vignetting
- Effective Area (C-K to Ge-K)
  - Direct on-/off-axis
  - „Glücksrad“ quasi parallel illumination
  - Continuum
- Focal length
  - X-ray
  - mechanical gage

Calibration of all 8 Mirrors
7 FM + 1 Flight spare
Completed end of May 2016

~ 2 weeks / mirror at PANTER

IACHEC, Lake Arrowhead, USA, March 29, 2017
Focus Search

vertex at  -45 +/- 100
HEW = 15.7 arcsec

chi2 = 74.68
deg of freedom = 10
confidence = 0.0 %

IACHEC, Lake Arrowhead, USA, March 29, 2017
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Focal Plane Mapping

\[ \text{Al K}\alpha \quad \text{HEW} = 16.3 \text{ arcsec} \]

\[ \text{Cu K}\alpha \quad \text{HEW} = 14.7 \text{ arcsec} \]

*images shown in log scale*

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Konrad Dennerl
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Effective Area Measurements

- Simulation Gluecksrad PANTER Geometry
- Simulation full illumination PANTER Geometry
- eRO-FM1-X6-CAL full illumination @cros-scan (TRoPIC)
- eRO-FM1-X6-CAL full illumination @Egger-Menz (TRoPIC)
- eRO-FM1-X6-CAL Continuum (TRoPIC)
- eRO-FM1-X6-CAL with Glueckrad (PSPC)

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On-/off-axis Effective Area: Vignetting

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Focal Plane Mapping $\rightarrow$ Vignetting

data from off-axis eff. area and focal plane mapping combined

IACHEC, Lake Arrowhead, USA, March 29, 2017
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  - X-ray
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Focal Length

(1) X-Ray Calibration

(2) Mounting into Telescope Structure

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Peter Friedrichc
Focal Length Gauge (Vacuum Proof)
Summary of the eROSITA Calibration

Mirror Assembly Results

<table>
<thead>
<tr>
<th></th>
<th>FM1</th>
<th>FM2</th>
<th>FM3</th>
<th>FM4</th>
<th>FM5</th>
<th>FM6</th>
<th>FM7</th>
<th>FM8</th>
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</thead>
<tbody>
<tr>
<td>HEW Al-Kα @ 1.49 keV</td>
<td>17.0</td>
<td>16.0</td>
<td>15.5</td>
<td>15.9</td>
<td>16.5</td>
<td>16.1</td>
<td>15.6</td>
<td>17.1</td>
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<tr>
<td>HEW Cu-Kα @ 8.04 keV</td>
<td>14.7</td>
<td>14.5</td>
<td>15.1</td>
<td>16.3</td>
<td>15.6</td>
<td>16.1</td>
<td>15.1</td>
<td>17.8</td>
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<tr>
<td>Eff. Area @ Al-Kα</td>
<td>392</td>
<td>391</td>
<td>393</td>
<td>369</td>
<td>388</td>
<td>378</td>
<td>392</td>
<td>390</td>
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<tr>
<td>Eff. Area @ Cu-Kα</td>
<td>24.8</td>
<td>24.8</td>
<td>25.1</td>
<td>23.8</td>
<td>24.1</td>
<td>25.1</td>
<td>24.0</td>
<td>24.2</td>
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<tr>
<td>Scattering @ Cu-Kα</td>
<td>10.2</td>
<td>11.1</td>
<td>11.0</td>
<td>12.1</td>
<td>13.2</td>
<td>11.2</td>
<td>12.8</td>
<td>12.3</td>
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</table>

Camera Calibration Results for Spectral Resolution [eV]

<table>
<thead>
<tr>
<th></th>
<th>FM1</th>
<th>FM2</th>
<th>FM3</th>
<th>FM4</th>
<th>FM5</th>
<th>FM6</th>
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<tbody>
<tr>
<td>C-Kα @ 0.277 keV</td>
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<td>58</td>
<td>58</td>
<td>58</td>
<td>50</td>
<td>59</td>
<td>58</td>
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<tr>
<td>O-Kα @ 0.525 keV</td>
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<td>65</td>
<td>64</td>
<td>64</td>
<td>57</td>
<td>69</td>
<td>66</td>
<td>53%</td>
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<tr>
<td>Cu-L @ 0.93 keV</td>
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<td>74</td>
<td>70</td>
<td>70</td>
<td>68</td>
<td>71</td>
<td>72</td>
<td>89%</td>
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<tr>
<td>Al-Kα @ 1.49 keV</td>
<td>77</td>
<td>82</td>
<td>77</td>
<td>77</td>
<td>75</td>
<td>77</td>
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<tr>
<td>Ti-Kα @ 4.51 keV</td>
<td>117</td>
<td>125</td>
<td>118</td>
<td>118</td>
<td>116</td>
<td>120</td>
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<tr>
<td>Fe-Kα @ 6.40 keV</td>
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<td>145</td>
<td>138</td>
<td>138</td>
<td>135</td>
<td>141</td>
<td>142</td>
<td>99%</td>
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<tr>
<td>Cu-Kα @ 8.04 keV</td>
<td>156</td>
<td>167</td>
<td>158</td>
<td>158</td>
<td>155</td>
<td>159</td>
<td>163</td>
<td>100%</td>
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<tr>
<td>Ge-Kα @ 9.89 keV</td>
<td>175</td>
<td>204</td>
<td>178</td>
<td>173</td>
<td>170</td>
<td>180</td>
<td>182</td>
<td>98%</td>
</tr>
</tbody>
</table>

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eROSITA Status

Jan – Jun 2016 PANTER / PUMA
The 7 FM Mirrors Assemblies and 7 Cameras have all been calibrated
→ the calibration results are currently being fed into the SASS

Jun - Aug 2016 MPE
all 7 Mirrors and 7 Cameras
→ Integrated into the telescope structure.

Sep – Nov 2016
the complete eROSITA with all 7 Telescope was tested
→ Camera cooling, Thermal control, Communication, Electronics, CCDs

Dec 2016 IABG
last environmental tests (vibration, EMC)

Jan 2017 → delivery to Russia, post transport tests → all ok
2017 → integration and testing of eROSITA on satellite platform

2018 → Launch from Baikonur
2018 → Commissioning and Cal Perf. Verif. → thereafter survey begin

IACHEC, Lake Arrowhead, USA, March 29, 2017
Ground Based Telescope Cross Calibration of Spectr-XG (eROSITA and ART-XC)

In the spirit of simplifying in-orbit cross-calibration

A plan is being setup for a ground based cross-calibration of the eROSITA and ART-XC spare mirror and spare detector units at PANTER. This will be done to ensure that the calibration of overlapping 6-10 keV spectral region is well understood.

In PANTER it will be possible to automatically switch between mirrors and detectors in the beam.

This is taking the IACHEC philosophy to the pre-launch phase of a new mission.