THE BEAUTY OF THE HIDDEN UNIVERSE
THE eROSITA X-RAY SKY SURVEY
• X-ray telescope on-board the Russian/German mission Spektrum-RG
• eROSITA is a German instrument, developed and manufactured at the MPE Garching in collaboration with the universities of Tübingen, Hamburg, Potsdam, Bonn and Bamberg
• There is also a Russian instrument on-board Spektrum-RG: ART-XC
• In development since: 2005
• Successfully launched: 13.7.2019
• Orbit: L2 Halo Orbit

- extended Roentgen Survey with an Imaging Telescope Array -

Scientific Goals:
Four years of all-sky survey in X-rays, then 2-3 years pointed observations
Main area of interest: cosmology, structure formation in the universe
Observe 100,000 clusters of galaxies at different redshifts
DAS SPEKTRUM DES LICHTS

RADIO
MIKRO
INFRAROT
Sichtbar
UV
RÖNTGEN
GAMMA

100kHz 10MHz 1GHz 100GHz 10THz 1PHz 100PHz 10EHz 100EHz

1MHz 100MHz 1GHz 10GHz 1THz 100THz 10PHz 1EHz 100EHz

Wellenlänge

1km 100m 10m 1m 10cm 1cm 1mm 100µm 10µm 1µm 100nm 10nm 1nm 100pm 10pm 1pm 100fm

Dieses Licht erreicht den Boden

Absorption durch die Atmosphäre

100 %
0 %

Undurchsichtige Atmosphäre

Unendlich
Absorption of radiation in Earth’s atmosphere as a function of wavelength or energy. Below the black line less than 50% of the incoming radiation is seen. Inside the dark grey area less than 1% can be detected.
First X-rays seen from the Sun in 1948

Herbert Friedman
1916* – 2000 +

Edward Hulburt
1890* – 1982 +

=> other stars will be too faint to be observed
Discovery of Sco X-1 in 1962

Riccardo Giacconi
1931* - 2018

Start einer Aerobee 150 Rakete

Bruno Rossi
1905* – 1993 +
EVIDENCE FOR X RAYS FROM SOURCES OUTSIDE THE SOLAR SYSTEM*

Riccardo Giacconi, Herbert Gursky, and Frank R. Paolini
American Science and Engineering, Inc., Cambridge, Massachusetts
- 2018

and

Bruno B. Rossi
Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received October 12, 1962)

Data from an Aerobee rocket carrying a payload consisting of three large area Geiger counters have revealed a considerable flux of radiation in the night sky that has been identified as consisting of soft x rays.

The entrance aperture of each Geiger counter consisted of seven individual mica windows com-
Erste Raketenflüge mit Geigerzählern und Kollimatoren ausgerüstete Raketenspitze

Discovery of Sco X-1 in 1962

Riccardo Giacconi


Riccardo Giacconi 1931*  


The entire experiment consisted of taking repeated measurements of the background radiation and the signal from the source. The data were then analyzed using a special algorithm designed to reduce the number of false detections. This allowed the team to determine the position of the source with high accuracy, confirming its location in the Scorpius constellation.
First X-ray satellite: UHURU sky survey (1970)

=> 339 sources, still with collimators (non-imaging)
focusing from a large collection area onto a small detector also brings a huge gain in sensitivity
X-ray Optics

=> Wolter Type-I X-ray mirror nested shells
ROSAT (1990): very successful first imaging all-sky survey (145,000 sources)
The Present Situation

Many small and large X-ray satellites have been (and are still) flown, each with a focus on different energy bands, imaging, timing, and spectroscopy studies.

- There are over a million detected sources of X-ray radiation in the sky.
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- There are over a million detected sources of X-ray radiation in the sky.
eROSITA mission history

- **ROSAT** 1990-1998:
  - First X-ray all-sky survey with an imaging telescope

- **Abrixas** 1999:
  - 7 telescopes
  - Goal: repeat the survey at higher energies
  - Failed directly after launch

- **ROSITA** 2002:
  - ROSITA: ABRIXAS on the International Space Station
  - Was not selected

- **eROSITA**:
  - On-board SPEKTR-RG
  - Goal: repeat the survey at higher energies + higher sensitivity
  - $10^5$ Galaxy Clusters, millions of AGN
  - 7 telescopes

- **DUO** 2004:
  - Dark Universe Observatory
  - $10^4$ Galaxy Clusters
  - SMEX-proposal in the US was not selected
**eROSITA mission history**

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**SRG definition**
(1990-2002)

**Mission development**
(2002-2006)

**UR-SRG/Abrixas**
(multiple iterations)

**DUO** 2004

**ROSITA (1990-1999)**

**ABRIXAS (1999)**

**Spectr-family**

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ROSITA: ABRIXAS on the International Space Station was not selected

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**DUO** 2004
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eROSITA telescope

Commissioning results

- Navigator platform has worked according to plan
- Pointing stability better than expected
- Radiocomplex science downlink has provided data with a very low error rate <0.5%
- Sessions have lasted up to 3 hours of eROSITA data dump - would mean 600 MByte of data dump
ART-XC (IKI)
Navigator (NPO Lavochkin)
eROSITA (MPE)
Спектр-РГ
• Focal length: 1.6 m. **Field of view: 1 degree (diameter)**
• Half-Energy width (HEW) \(\sim 18''\) (on-axis, point.); \(\sim 26''\) (FoV avg., survey)
• Source location accuracy \(\sim 3-5''\)
• X-ray baffle (10\(\mu\)m precision alignment): 92% stray light reduction
• pnCCD with Framestore (no ‘out of time’ events), **no chip gaps**
• Extremely **good detector uniformity**, little temperature dependence
• **Spectral resolution** at all measured energies within specs (~80eV @1.5keV)
Camera shielded in 4 cm thick copper

Filter wheels with calibration sources
Camera shielded in 4 cm thick copper filters with calibration sources.
Baikonur kosmodrom

- First (1955) and largest rocket launch site in the world (kosmodrom) (into orbit, i.e. non-ballistic)
- 15 launch sites for 9 rocket types
- area of 6717 km2 (~3 Saarland)
- close to 3000 launches in total
  - SRG was 10th this year
- Built mainly to test R-7 ICBM
- Developed to what it is:
  - **Sputnik** (1957, start of space era)
  - **Sputnik-2** (1957, first creature in space)
  - **Vostok-1** (1961, first man in space)
  - **Vostok-6** (1963, first woman in space)
  - **Voschod-2** (1965, first spacewalk)
  - Buran/Energija (1988, first autonomous flight/landing)
- Currently rented by Russia from Kazakhstan (115 Musd/year if you’re interested)
- Still the main launch site in Russia
Launch on the 13th of July, 2019, 5:31 PM
credit Alexander Ivanov (Jun 13 21:13-02:40 Moscow time with Maksutov 243/1200)
Earth escape orbit
h/H = 500 x 1,293,041 km
i = 51.6°

Spacecraft separation
~ 17:30 Moscow Time

Block DM-03: 2nd engine firing
~ 17:07 - 17:16 Moscow Time
t = 9 min 27 sec
dV = 3,957.32 m/s

Stage III separation trajectory
H/h = 200.4 x -476.1 km
i = 51.51°

Block DM-03: 1st engine firing
~ 15:46 - 15:49 Moscow Time
t = 3 min 11 sec
dV = 695.93 m/s

Parking orbit
h/H = 170.0 x 1,927.7 km
i = 51.49°
T = 1 h 46 min 9 sec

Not to scale

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Launch with PROTON/BLOK-DM from Baikonur
Cruise to Lagrange 2
4 years survey, continuous rotation (~4hr)
3 years pointed observations
L2 Orbit

Sonne 150 Mill. km

Erde

L2
First Year of Operations
eROSITA First Light Image

7 Telescopes
eROSITA First Light Image
Highlights from CalPV phase

Merloni, Nandra, Predehl, Nat. Astr. (2020)
eROSITA's advantage

Moon diameter
30 arcmin

XMM-Newton
Field of view ~ 30 arcmin

Chandra
Field of view ~ 17 arcmin

Typical observation duration: 50 ks
=> impossible to look at the full sky
(41,200 square degrees)

eROSITA
Field of view ~ 62 arcmin

4 h per rotation
half a year for complete sky coverage

Scanning feature
eRASS:1, The first All-Sky Survey

• Started on December 13, 2019, after a 2-months long Calibration and Performance Verification Program
• Completed on June 11, 2020
• Uniform exposure ~200s; up to 36ks at the Ecl. Poles
• Almost no background flares, flexible mission planning: no gaps in exposure
• ~400 Million 0.12-5keV calibrated photons
• About 1 Million sources detected (~80% AGN; 20% Stars)
  • Almost doubled the number of known X-ray sources
• ~20k clusters, up to z~1
• Numerous transients discovered; fine tuning vetting mechanisms, followup resources
SRG/eROSITA 0.3-2.3 keV - RGB Map
Navigating the eROSITA X-ray sky

- Coma Cluster [99 Mpc]
- Virgo Cluster [17 Mpc]
- Vela SNR [250 pc]
- Large Magellanic Cloud [50 kpc]
- Sco X-1 [2.8 kpc]
- Cygnus Loop [770 pc]
- Centaurus Cluster [41 Mpc]
- Crab Pulsar [~2 kpc]
- Cas A [3.4 kpc]
- Cygnus Superbubble [1-2 kpc]
- Cyg X-1 [1.9 kpc]
- Cyg X-2 [600 pc?]
- G156.2+05.7 SNR [1.7-3 kpc]
- Perseus Cluster [74 Mpc]
- North Polar Spur
- Large Magellanic Cloud
- Fornax Cluster [250 pc]
- Orion Nebula [412 pc]
- Vela SNR [412 pc]
- MPE 40

- z=3.1 QSO [26 Gpc]
A few highlights from eRASS:1

eRASS:1 = eROSITA All-Sky Survey: first complete survey (there will be 8 in total)

1: Vela SNR [250 pc]
2: Large Magellanic Cloud [50 kpc]
3: Dust scattering echo
The Large Magellanic Cloud

LMC X-3

Foreground Star

SNR

SNRs

LMC X-4

SNRs

LMC X-1

SNR

LMC X-2

eROSITA First Light Image

F. Haberl, C. Maitra (MPE)

MPE

Merloni, EAS, 6/2020
Scan along the galactic plane
eROSITA data rights

Operations and ground segment
- Real time socket telemetry connection > OK
- Operational interface with IKI/NPOL > OK
- Operations concept is working (has been carried out by different people successfully)
- Needs more automatism
- Needs to be opened up to outside instrument team
### eROSITA at a glance

#### Instrument

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>1,9m Ø x 3.5m</td>
</tr>
<tr>
<td>Weight</td>
<td>810kg</td>
</tr>
<tr>
<td>Power</td>
<td>522W</td>
</tr>
<tr>
<td>Data volume</td>
<td>600MB/day</td>
</tr>
<tr>
<td>lifetime</td>
<td>&gt; 7 years</td>
</tr>
<tr>
<td>Launcher</td>
<td>PROTON/BLOK-DM</td>
</tr>
<tr>
<td>Launch</td>
<td>13. Juli 2019</td>
</tr>
<tr>
<td>Mission</td>
<td>Orbit around L2</td>
</tr>
</tbody>
</table>

#### 7 Mirror Assemblies

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of outer shell</td>
<td>358mm</td>
</tr>
<tr>
<td>Number of shells</td>
<td>54</td>
</tr>
<tr>
<td>focal length</td>
<td>1600mm</td>
</tr>
<tr>
<td>PSF/HEW on axis (1.5keV)</td>
<td>16 arcsec</td>
</tr>
<tr>
<td>HEW average FoV</td>
<td>26 arcsec</td>
</tr>
<tr>
<td>Effective Area (1.5keV)</td>
<td>350 cm²</td>
</tr>
<tr>
<td>Field of View</td>
<td>1°</td>
</tr>
</tbody>
</table>

#### 7 Camera Assemblies

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pnCCD + Filterwheel + E-Box</td>
<td></td>
</tr>
<tr>
<td>3 x 3 cm², pixel size 75µm x 75µm</td>
<td></td>
</tr>
<tr>
<td>384 x 384 Pixel</td>
<td></td>
</tr>
<tr>
<td>Time Resolution</td>
<td>50 msec</td>
</tr>
<tr>
<td>Energy Resolution (1keV)</td>
<td>~ 70eV</td>
</tr>
<tr>
<td>Quantum Efficiency (1keV)</td>
<td>~ 95%</td>
</tr>
</tbody>
</table>

#### Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Range</td>
<td>0.2-12keV</td>
</tr>
<tr>
<td>Point Source Sensitivity</td>
<td>1.2E-14</td>
</tr>
<tr>
<td>P.S. Sensitivity at poles</td>
<td>2.9E-15</td>
</tr>
<tr>
<td>Extended Source Sens</td>
<td>3.4E-14</td>
</tr>
<tr>
<td>ES. Sensitivity at poles</td>
<td>1.0E-14</td>
</tr>
</tbody>
</table>

### eROSITA_DE

- 12 working Groups
- 135 Members
- + External Collaborators
Follow us on Twitter: @eROSITA_SRG

You Tube: eROSITSA SRG

Thank you