Mapping Large Scale Structures at High Energies: First Results from eROSITA on SRG

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Outline

• SRG/eROSITA factsheet:
  – Scientific drivers
  – Brief history
  – Technical characteristics and mission profile

• First 9 months of science operations
  – Mission status, operations
  – Highlights from early Performance Verification observations
  – The all-sky survey
Clusters are exponentially sensitive tracers of growth of structures

A signature of clusters is the detection of hot (~10^7 K) X-ray ICM

eROSITA (PSF, sensitivity) was designed to be able to detect >10^5 clusters (Pillepich+ 2018)

The Virgo Collaboration; Jenkins et al. 1998

Merloni, 4th Zeldovich, 9/2020
eROSITA on Spektr-RG

eROSITA PI: P. Predehl -> A. Merloni
SRG Lead Scientist in RU: R. Sunyaev
HEG Director: K. Nandra

Core Institutes (DLR funding):
MPE, Garching/D
Universität Erlangen-Nürnberg/D
IAAT (Universität Tübingen)/D
HS (Universität Hamburg)/D
Astrophysikalisches Institut Potsdam/D

Associated Institutes:
MPA, Garching/D
IKI, Moscow/Ru

Industry:
Media Lario/I
Kayser-Threde/D
Carl Zeiss/D
Invent/D
pnSensor/D
IberEspacio/E
RUAG/A
HPS/D,P
+ many small companies

Mirrors, Mandrels
Mirror Structures
ABRIXAS-Mandrels
Telescope Structure
CCDs
Heatpipes
Mechanisms
MLI

MPE: Scientific Lead Institute, Project Management
Instrument Design, Manufacturing, Integration & Test
Data Handling & Processing, Archive etc.
Radiators
(passive cooling of cameras and electronics)

(2) Star trackers

7 Mirror Assembly

7 Cameras
7 Mirrors + pnCCDs

- 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 (10μm precision alignment): 92% stray light reduction
- pnCCD with Framestore (no ‘out of time’ events), no chip gaps
- Extremely good detector uniformity, little Temperature dependence

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Effective Area and Grasp

Effective Area: \(~1300\, \text{cm}^2\) (FoV avg. @1keV)

- Effective area at 1keV comparable with XMM-Newton
Effective Area and Grasp

Grasp: ~1000 cm² deg² (@1keV)
eROSITA's advantage

- **Grasp @1keV:**
  - $5 \times$ XMM-Newton
  - $100 \times$ Chandra ACIS
  - 4 years fully dedicated to all-sky survey

- **Moon diameter:** 30 arcmin
- **XMM-Newton Field of view:** ~ 30 arcmin
- **Chandra Field of view:** ~ 17 arcmin
- **eROSITA Field of view:** ~ 62 arcmin
- **Scanning feature**
Baikonur, July 13th, 2019
SRG/eROSITA Operations

Courtesy of D. Coutinho (MPE)

Ground station (Bear Lakes & Ussuriy sk)

Mission Control (NPO Lavochkin)

Ground Segment (IKI)

Cosmos exchange Server (IKI)

Telemetry socket connection for real time data during ground contact SENS, MPD, KNA data

SIP phone

eROSITA commands

eROSITA Telemetry

AFS data server (MPE)

DS53 data server (MPE)

Station 1
Main operations & socket interface Nominal

Station 2
Housekeeping display & socket interface Redundant

Station 3
CCD science data display

Station 4
Housekeeping display

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1) Background much less variable than in the XMM and Chandra data
2) A factor of ~3 higher particle background than predicted in the White Book
3) Less fluorescence lines than EPICpn due to graded shields
4) Nevertheless an iron line (+ others) whose origin is not completely clear
First light: LMC

SRG/eROSITA (0.2-4.5 keV)

LMC/SN1987A; 80ks

Credit: F. Haberl, M. Freyberg, C. Maitra
- excellent sensitivity to diffuse and point-like sources
- power of the large FOV
Highlights from CalPV phase

Merloni, Nandra, Predehl, Nat. Astr. (2020)
eFEDS: a sky preview at the final survey depth

140 deg$^2$; ~2.5ks exposure; Brunner, Lamer, Liu et al., in prep.

Credit: H. Brunner, M. Ramos-Ceja

Exposure corrected image in the 0.5–2.0 keV band

MPE/IKI
More than 400 galaxy clusters detected by eROSITA (Bulbul et al. in prep.)

~ 370 already optically confirmed, 0.1<z<1.1 (Klein, Mohr et al. in prep.)
eFEDS AGN

- More than 25k point-sources detected (Salvato et al. In prep.)
- 85% AGN; 15% coronal stars
- ~8000 spectroscopic redshift of AGN, including ~3800 from a dedicated SDSS-IV/SPIDERS program

Credit: H. Brunner, M. Ramos-Ceja

Exposure corrected image in the 0.5–2.0 keV band
- **4 years**: 8 all sky surveys (eRASS:1-8; scanning mode: 6 rotations/day)
- **2.5 years**: pointed observations, including TBD GTO quota. 1 AO per year
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 double the number of known X-ray sources
- ~20k clusters, up to z~1
- Numerous transients discovered; fine tuning vetting mechanisms, followup resources
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
- Cyg X-1: 1.9 kpc
- Cygnus Loop: 770 pc
- Cas A: 3.4 kpc
- Cygnus Superbubble: 1-2 kpc
- G156.2+05.7 SNR: 1.7-3 kpc
- Perseus Cluster: 74 Mpc
- Cyg X-2: 600 pc
- Centaurus Cluster: 41 Mpc
- Shapley Supercluster: 200 Mpc
- Crab Pulsar: ~2 kpc
- Orion Nebula: 412 pc
- Vela SNR: 412 pc
- Fornax Cluster: 250 pc
- Large Magellanic Cloud: 19 Mpc

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A few highlights from eRASS:1

Dust scattering echo

Vela SNR [250 pc]

Large Magellanic Cloud [50 kpc]
The Large Magellanic Cloud

SRG/eROSITA

LMC X-3

Foreground Star

SNR

SNRs

LMC X-4

SNRs

LMC X-1

SNR

LMC X-2

eROSITA First Light Image

3 degrees

F. Haberl, C. Maitra (MPE)

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eRASS:8, the legacy

• All clusters more massive than \( \sim 2 \times 10^{14} M_\odot \)

• \( > 3 \) Million AGN (\(<z>\sim 1 \) and \(<Lx>\sim 10^{44} \text{ ergs/s} \))

• Compact objects (NS, BH) population of the Milky Way

• Population study of 750k active (young, magnetic) stars

• Nearby star-forming galaxies and galaxy groups

• Dynamical view of the X-ray sky and identify transients and variable sources, including hundreds of TDEs

• Serendipity…