The eROSITA X-ray all-sky survey

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On behalf of Mara Salvato and the eROSITA team
Outline

● Galaxy clusters: an introduction
● The eROSITA instrument on SRG
● Survey design
● Constraining dark energy with eROSITA
● Additional science (AGN, TDEs, ...)

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Galaxy clusters: an introduction

- The galaxies only account for ~1 % of a cluster's mass.
- The hot intracluster medium contains 90 % of the baryons and ~15 % of the mass.
- Gravitational lensing traces the total mass distribution (including dark matter).
- The bullet cluster (Markevitch et al. 2002, Clowe et al. 2006).
Formation and evolution of a galaxy cluster
The halo mass function and its cosmological dependence

Springel et al. 2006
Dark energy with a galaxy cluster survey

- The growth rate of galaxy clusters depends on the expansion rate, hence on dark energy

![Graph showing the growth rate of galaxy clusters](image)

Roncarelli et al. 2006
Rosati et al. 2002

\[ n(>M,z)/n(>M,0) \]

- \( \Omega_m = 0.3 \)
- \( \Omega_\Lambda = 0 \)
- \( \Omega_m = 0.3 \), \( \Omega_\Lambda = 0.7 \)

\( M > 5 \times 10^{14} h^{-1} M_\odot \)

Redshift
Mapping the structure of the hot Universe

Diffuse X-ray emitting gas traces the massive knots of the cosmic web (Clusters)

Point sources (Quasars) signpost the growth of black holes

Simulation of an eROSITA field
Spectrum-Roentgen-Gamma

- eROSITA (MPE)
- ART-XC (IKI)
- Navigator (Lavochkin Ass.)
- Fregat-SB Booster + Launcher + Ground Segment
eROSITA: the Project

PI: Peter Predehl; PS: A. Merloni (MPE)

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

Associated Institutes:
MPA, Garching/D
IKI, Moscow/Ru
USM (Universität München)/D
AIA (Universität Bonn)/D

Industry:
Media Lario/I Mirrors, Mandrels
Kayser-Threde/D Mirror Structures
Carl Zeiss/D ABRIXAS-Mandrels
Invent/D Telescope Structure
pnSensor/D CCDs
IberEspacio/E Heatpipes
RUAG/A Mechanisms
HPS/D,P MLI
+ many small companies

COSTS: ~80-90 M€ (eROSITA)
~250-300 M€ (SRG)

MPE: Scientific Lead Institute, Project Management
Instrument Design, Manufacturing, Integration & Test
Data Handling & Processing, Archive etc.
7+1 Mirror assemblies

- 54 nested gold-coated nickel mirror shells
- Focal length: 1.6 m, Field of view: 1 degree (diameter)
- On-axis Half-Energy width (HEW) ~16.1” (nominal)
- X-ray baffle (10μm precision alignment): 92% stray light reduction
- Calibration of all 8 telescopes at PANTER completed in June
Point Spread Function

Al Kα (1.49 keV)
HEW = 18.1“ (on axis)
~ 24.8“ (FoV avg.)

Cu Kα (8 keV)
HEW = 15.4“ (on axis)
~ 42“ (FoV avg.)
7+1 Framestore pnCCD

Meidinger et al, 9144E..1WM
Cameras Calibration

- **3.3 Billion** calibrated events! (K. Dennerl, N. Meidinger)
- **Spectral resolution** at all measured energies within specification (R~20 @1.5keV)
- Extremely good **uniformity**
- Only weak dependence on CCD and electronics temperature (unlike XMM)
- Very accurate absolute energy reconstruction (<0.06%)

\[
\begin{align*}
\Delta E &= 49\text{eV} @ 0.28\text{keV} \\
&= 77\text{eV} @ 1.5\text{keV} \\
&= 136\text{eV} @ 6.4\text{keV}
\end{align*}
\]
Effective Area and Grasp

Effective Area: \(~1700\ \text{cm}^2\) (FoV avg. @1keV)

- Effective area at 1keV comparable with XMM-Newton
- Factor \(~7\text{-}8\) larger surveying speed
- 4 years dedicated to all sky survey (with estimated 70\text{-}80\% efficiency)
- XMM-quality data over the whole sky!
**SRG: Mission timeline**

- **eROSITA delivery to Russia:** January, 2017
- **Launch:** June-August 2019 from Baykonour
- **3 Months:** flight to L2, PV and calibration phase
- **4 years:** 8 all sky surveys eRASS:1-8 (scanning mode: 6 rotations/day). Re-visit LMC & SMC every ~month (down to $L_{0.5-2 \text{ keV}} \sim 10^{34}$ erg/s)
- **3.5 years:** pointed observation phase, including ~20% GTO. 1 AO per year
eROSITA surveys in context

All sky: $10^{-14}$ (0.5-2 keV)
$2 \times 10^{-13}$ (2-10 keV) [erg/cm$^2$/s]

Merloni et al. 2012

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All massive clusters

- 110k clusters with >50 net counts (“secure” detections, Pillepich et al. 2018)
- 23k clusters with accurate redshift determination from X-ray alone
- ~2k clusters with accurate temperature determination from X-ray spectra

Grandis et al. 2018
From X-ray photons to cosmology

- eROSITA photon map
- External Datasets: Subaru/HSC, DES, SDSS, 4MOST...
- Halo Mass Function

Diagram:
- Source Detection
- Cluster Identification
- Mass Calibration
- Weak Lensing
- Mass Proxies
- Selection Function
Weak lensing mass calibration

- Weak gravitational lensing is the best way of calibrating the mass scale of eROSITA clusters

Subaru-HSC will provide mass calibration of ~2,000 eROSITA clusters with a precision of 2%
Dark energy forecasts

Pillepich et al. 2018

Grandis et al. 2018

eROSITA will bring the first constraints on time evolution of the dark energy equation of state
3 Million AGN: Physics and Cosmology

- Population studies
- The most luminous AGN, tracers of large scale structure: the “quasar” mode of AGN feedback
- (Obscured) accretion history
- High-z AGN
- Huge effective volume, BAO signal with biased tracers
- SED vs. L, L/L_{EDD}

\[<z>=1\]

\[<L_x>=10^{44}\]

Effective Volume
Spectroscopic follow-up

- **SDSS-V (2020-2024) [www.sdss.org/future/](http://www.sdss.org/future/)**
  - ‘Black Hole Mapper’ (BHM): SDSS + LCO full-sky coverage complete follow-up of eRASS:3:
    - over ~10,000 deg$^2$ (250k AGN spectra to r=21.5, 80k galaxies in 10k clusters)

- **VISTA/4MOST (2023-2027) [www.4most.eu](http://www.4most.eu)**
  - Complete, systematic follow-up of both Clusters and AGN from eROSITA: reach >80% completeness for eRASS:8 (down to r~22.8)
  - ~700k AGN spectra 0<z<6
  - ~1M galaxies in ~50k X-ray selected clusters (Clusters clustering, RSD, velocity dispersion, gravitational redshift)
>100 TDEs per month...

# of TDEs in ONE eROSITA all-sky survey (6 months)

$N_{\text{tot}} = 1237$

$N_{\text{tot}} = 765$

$N_{\text{tot}} = 670$
And More…

• Provide a detailed view of the compact objects (NS, BH) population of the Milky Way
• Survey of 600k active (young, magnetic) stars
• Map the diffuse X-ray emission and the hot ISM in the Milky Way and in the Solar neighborhood
• Study nearby star-forming galaxies and galaxy groups
• Provide a dynamical view of the X-ray sky and identify transients and variable sources, including 1000’s TDEs
• Serendipity…

Working with eROSITA

- eROSITA is a PI instrument
  - Scientific exploitation of data shared between the partners: 50% MPE and 50% IKI, West/East (gal. coord.)
  - German data public after 2 years, 3 releases (‘20, ‘22, ‘24; TBC)
  - Proprietary access via eROSITA_DE (/RU) consortium
  - Projects/papers regulated by working groups

- Working Groups:
  - Science: Clusters/Cosmology, AGN, Normal galaxies, Compact objects, Diffuse emission/SNR, Stars, Solar System, Time Domain Astrophysics
  - Infrastructure: Data analysis and catalogues, Multiwavelength follow-up, Calibration, Background

- Collaboration policy:
  - Individual External Collaborations (proposal to WGs)
  - Group External Collaborations (team-to-team MoUs)
RASS (ROSAT) vs. eROSITA vs. XMM

Image credits: MPE, eRosita_DE consortium, XMM-XXL
Sky coverage of selected wide area surveys - ALL bands

12ʰ Equatorial Hemisphere

0ʰ Equatorial Hemisphere

Dust E(B-V) eRASS Texp

>1.0  >10ks

>0.5  >7.5ks

>0.3  >5ks

>0.2  >3ks

都要 E(B-V) eRASS Texp

>0.1  >1ks

Central (RA,DEC)=(180⁺,0⁰)

Central (RA,DEC)=(0⁰,0⁰)

Subaru-HSC
OGLE-IV
PanSTARRS
SkyMapper
eRosita-DE
J2000 grid
Galactic grid

(2000 Coords, Zenithal Equal Area Projection (radius=200°)