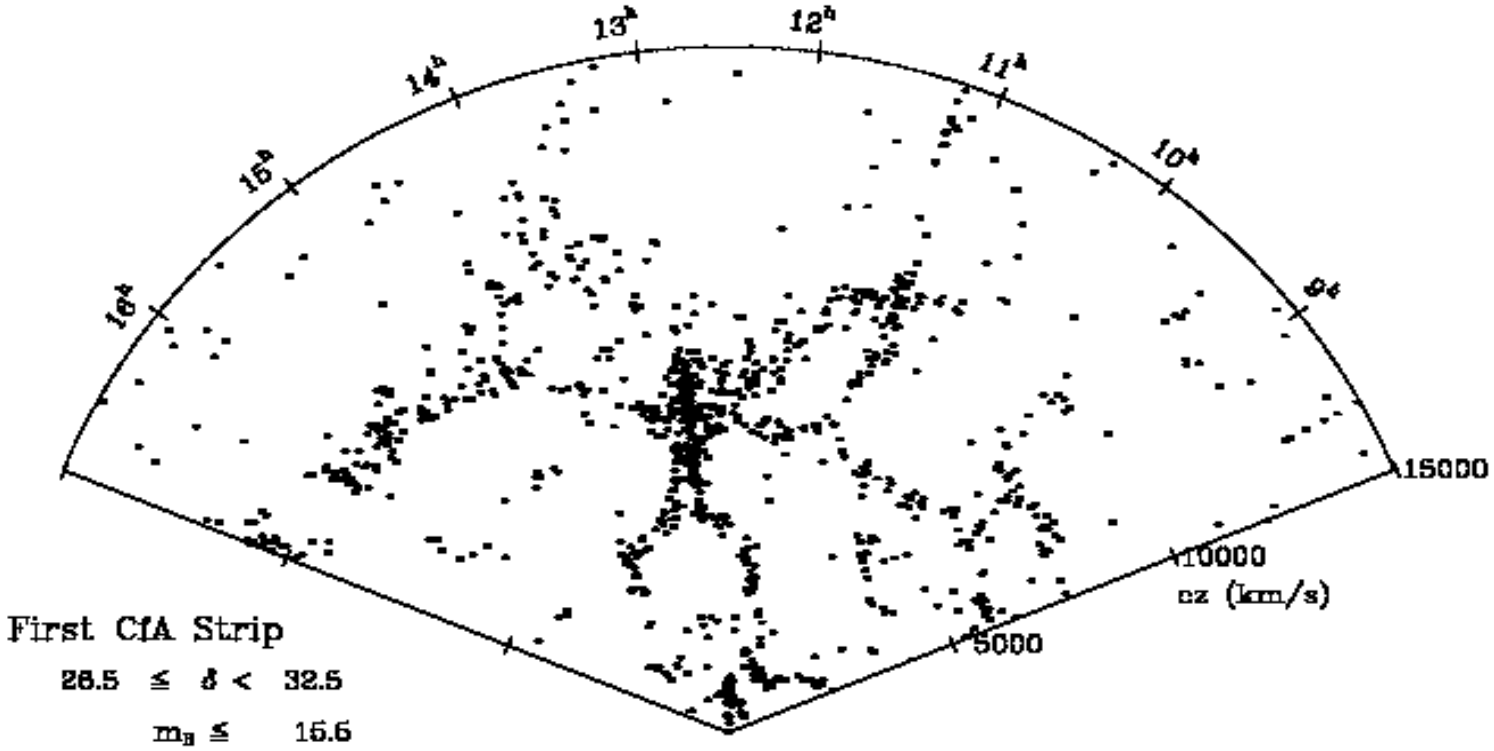
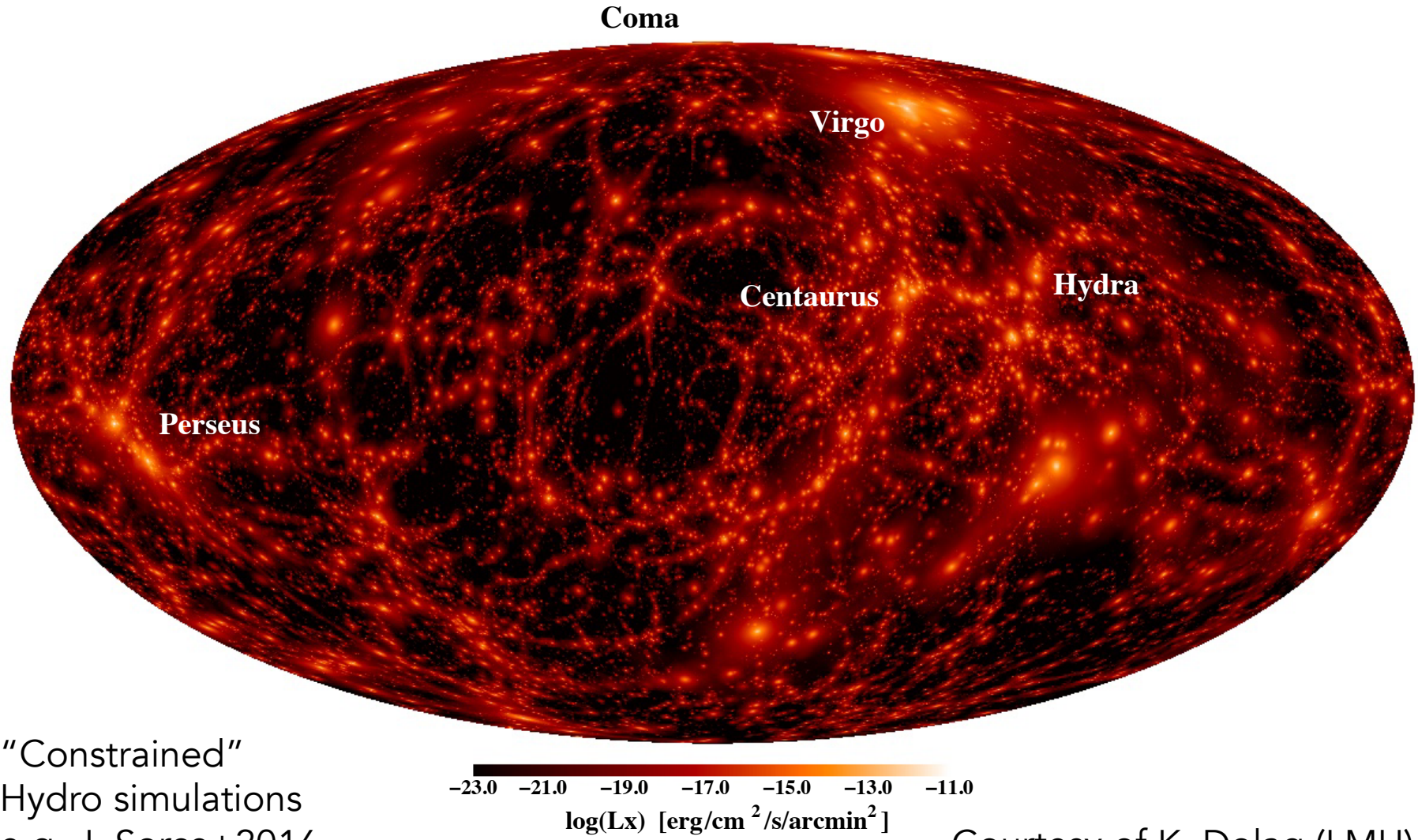
eROSITA on SRG:
Towards the promised land of high-energy catalogs treasure hunters

Andrea Merloni (MPE)

Mapping the Universe



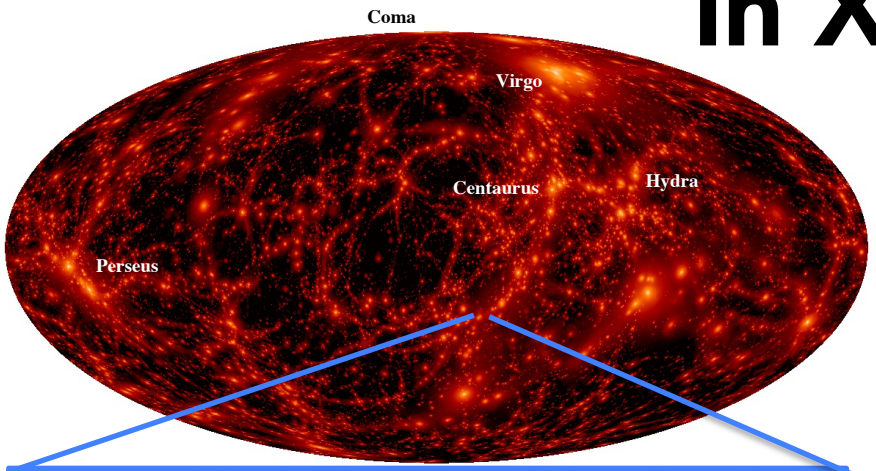
Mapping the Universe

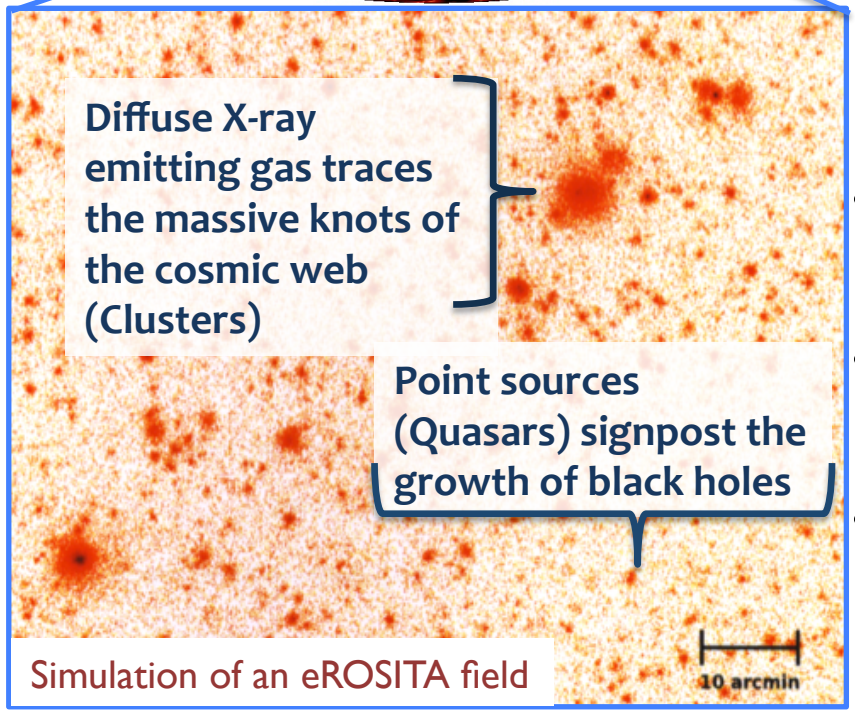


"Constrained"
Hydro simulations
e.g. J. Sorce+2016

Courtesy of K. Dolag (LMU)

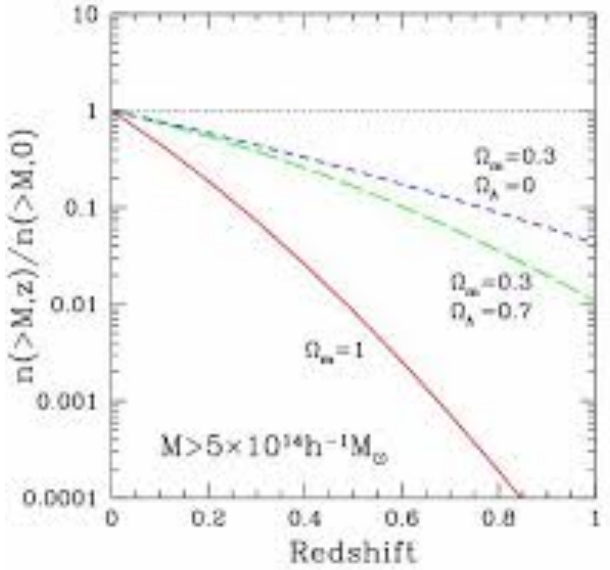
Mapping the Universe In X-rays





Simulation of an eROSITA field

Images coutesy of K. Dolag (LMU), M. Mühlegger (MPE), O. Hahn (ETH)



Rosati, Norman, Borgani 2002

- A signature of clusters is the detection of hot (~10^7 K) ICM
- Clusters are *exponentially sensitive* tracers of **growth of structures**
- Cosmological constraints with (well calibrated) ROSAT samples ~100 obj.

eROSITA: the Project

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

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

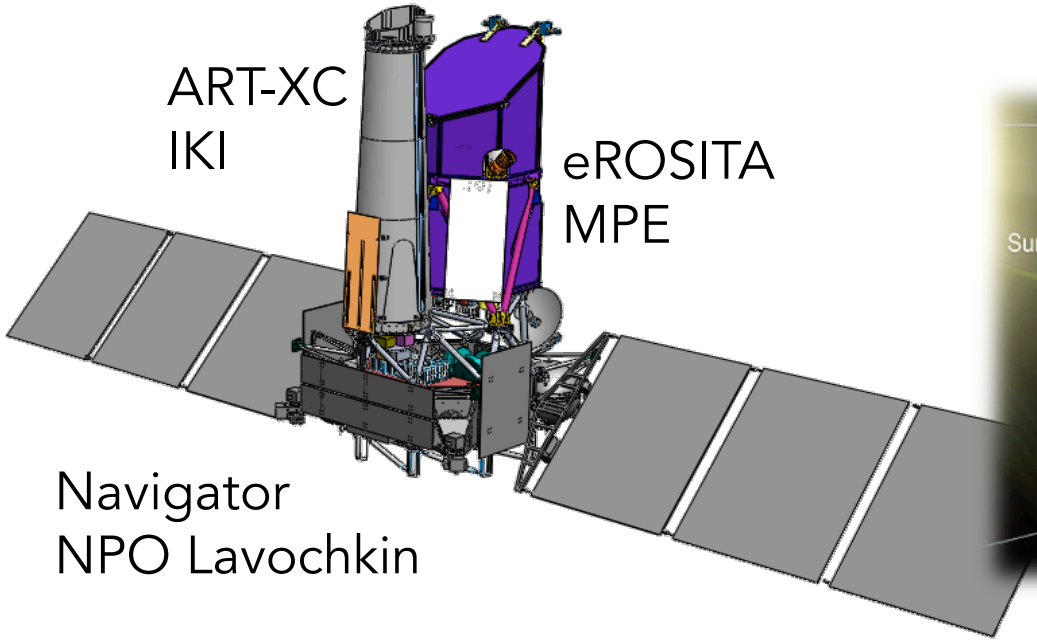
Associated Institutes:
MPA, Garching/D
IKI, Moscow/Ru
USM (Universität München)/D
AIA (Universität Bonn)/D

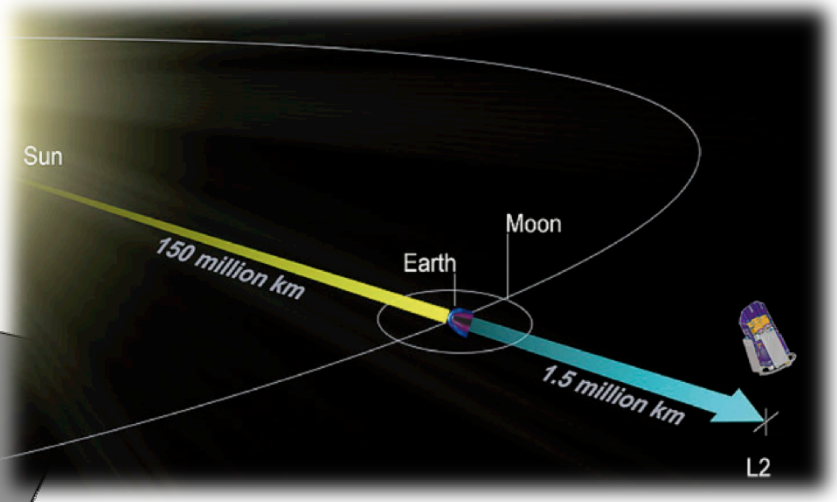
Industry:
Media Lario/I Mirrors, Mandrels
Kayser-Threde/D Mirror Structures
Carl Zeiss/D ABRIXAS-Mandrels
Invent/D Telescope Structure
pnSensor/D CCDs
IberEspacio/E Heatpipes
RUAG/A Mechanisms
HPS/D,P MLI
+ many small companies

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

MPE: Scientific Lead Institute, Project Managment
Instrument Design, Manufacturing, Integration & Test
Data Handling & Processing, Archive etc.

SRG: Mission Profile



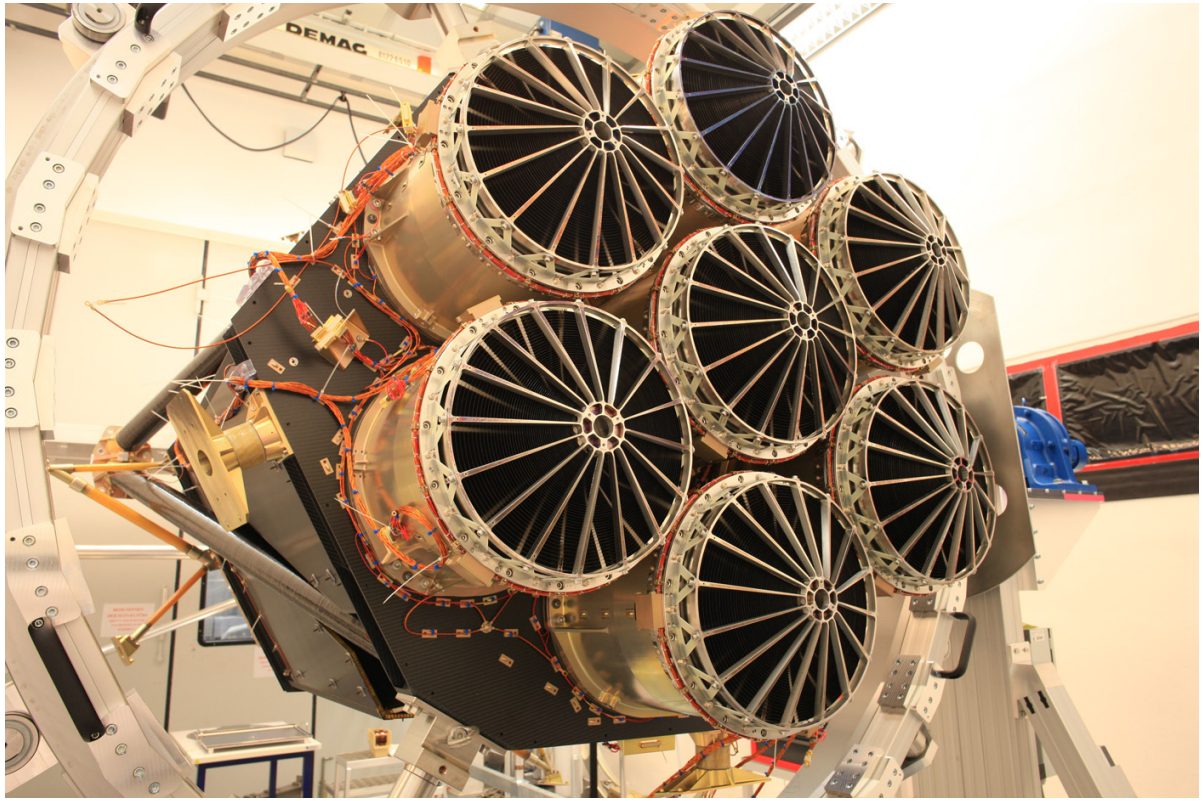


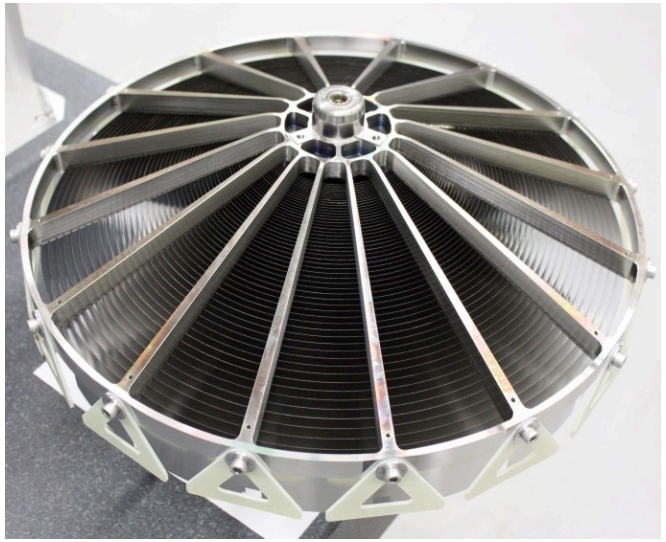
- **Launch**: From Baykonour, Proton–Block-DM
- **3 Months**: flight to L2, PV and calibration phase
- **4 years**: 8 all sky surveys (**eRASS:1-8**; scanning mode: 6 rotations/day)
  - Re-visit LMC & SMC every ~month (to $L_{0.5\text{-}2\ keV} \sim 10^{34}$ erg/s)
- **2.5 years**: pointed observations, including ~20% GTO. 1 AO per year
- **Ground Segment**: 2 x 70m antennas (Bear Lakes and Ussirisk), daily contact (up to ~4 hours); telemetry transfer directly to MPE via Moscow NPOL/IKI Control Center

eROSITA is ready!

- End to end, qualification tests completed in 12/2016
- Shipped to Moscow in 01/2017, integration/tests ongoing
- ALL Flight hardware on site, first full integration and interface test ungoing (till end of May)
- Packaging and transport to Baykonour ~Jan. 2019
- **Launch in March/April 2019**

7+1 Mirror assemblies

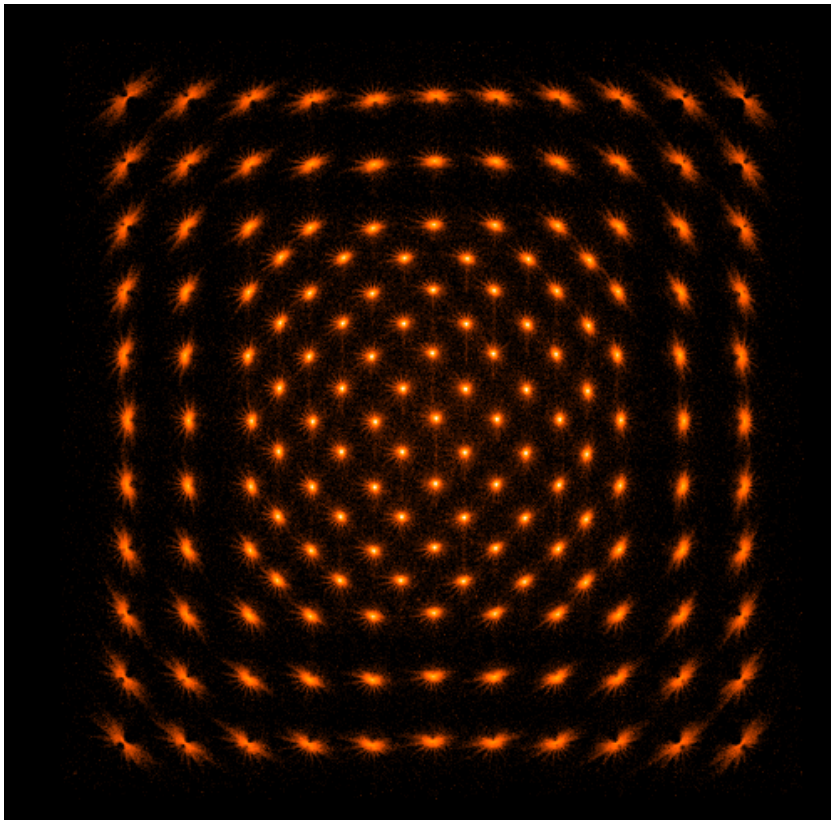




X-ray Baffle [MPE]

- 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 2016

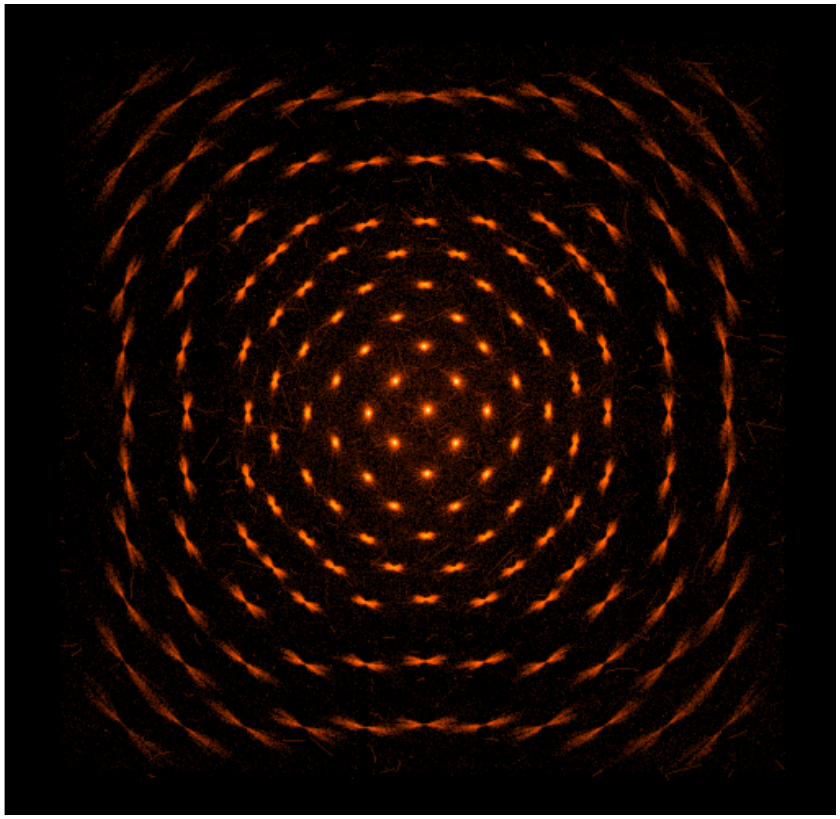
Focal Plane Mapping



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.)

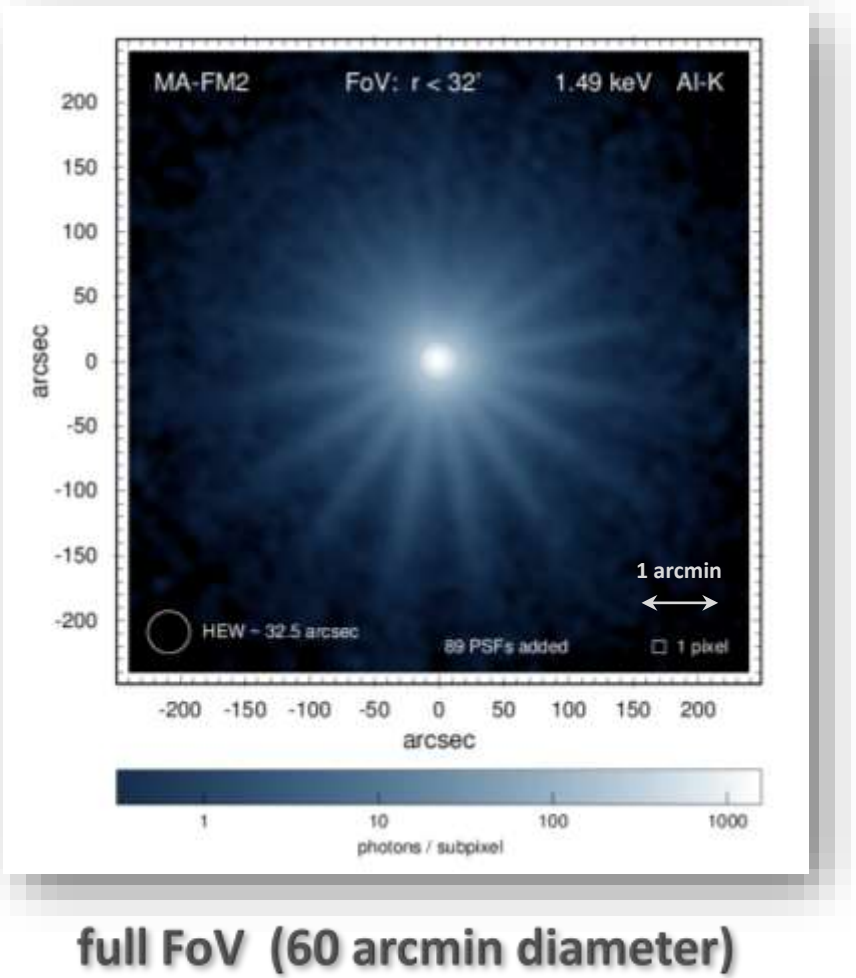
Preview of the eROSITA Survey PSF

0.28 keV (C-K) **1.49 keV (Al-K)** 4.51 keV (Ti-K) 6.40 keV (Fe-K) 8.04 keV (Cu-K)

Antonis Georgakakis

Latest shapelet reconstruction of the eROSITA PSF measured at the PANTER.

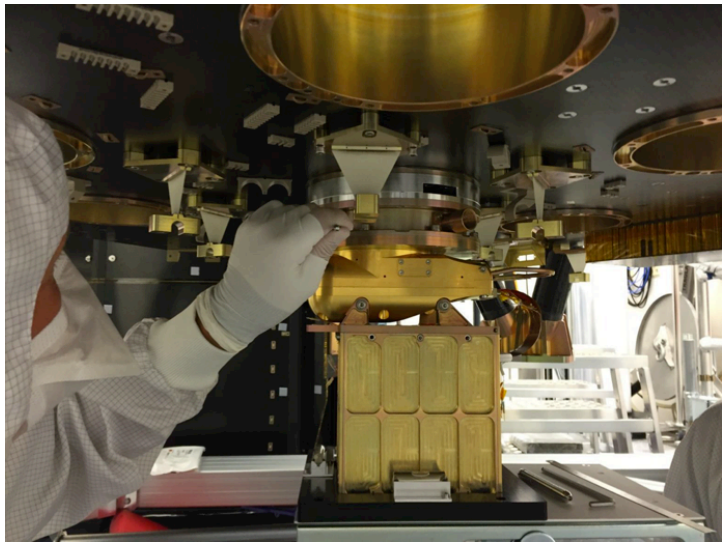
- Flux integration within pixels (account for pixelisation)
- 3 shapelet scales used to fit the core and wings of the PSF (112 free parameters per PSF)

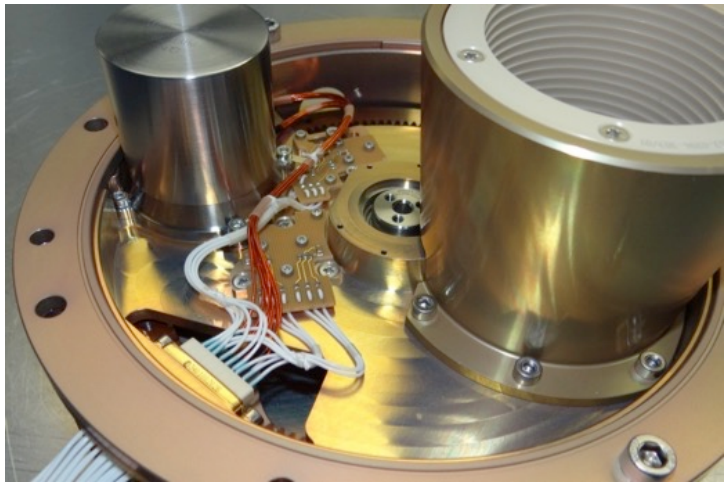


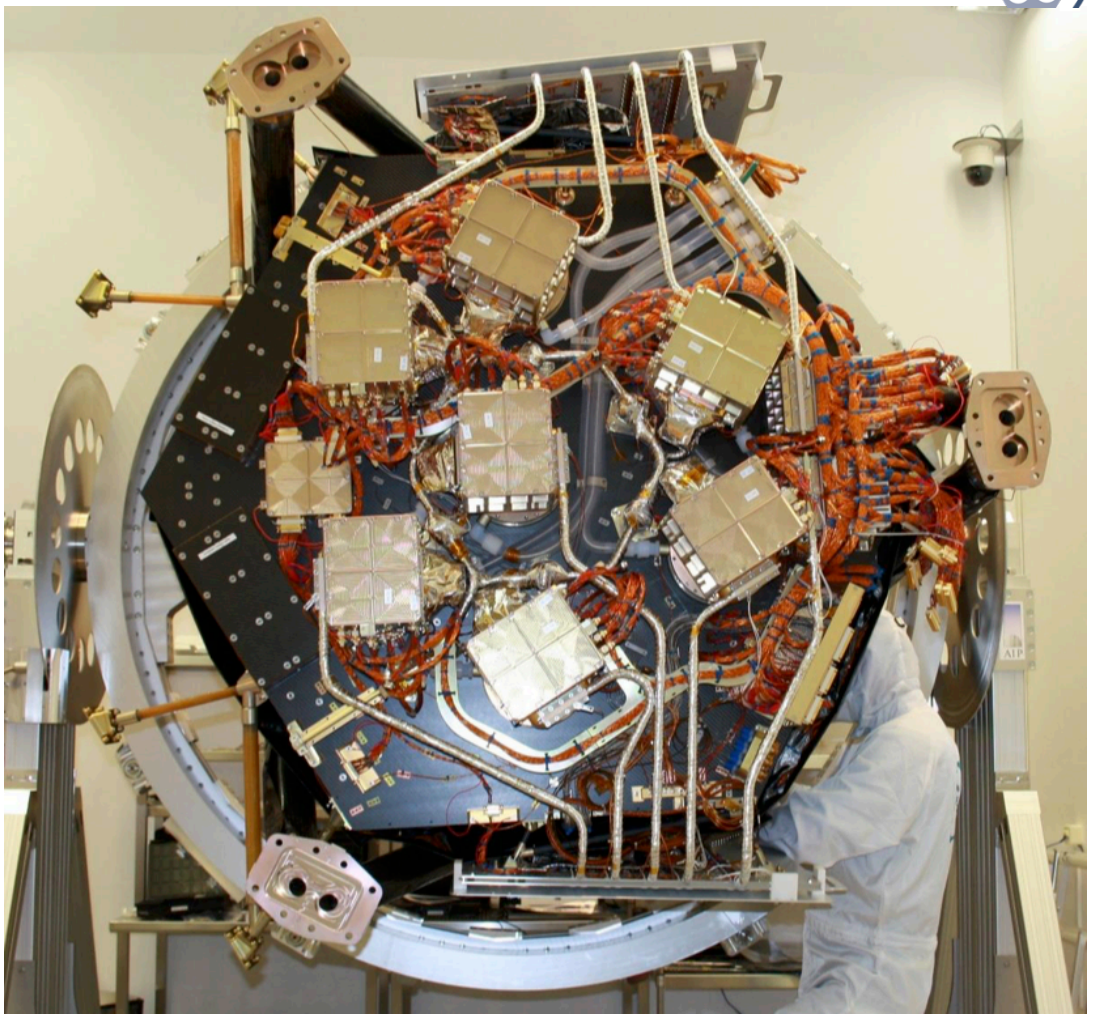
full FoV (60 arcmin diameter)

K. Dennerl (MPE)

7+1 Framestore pnCCD



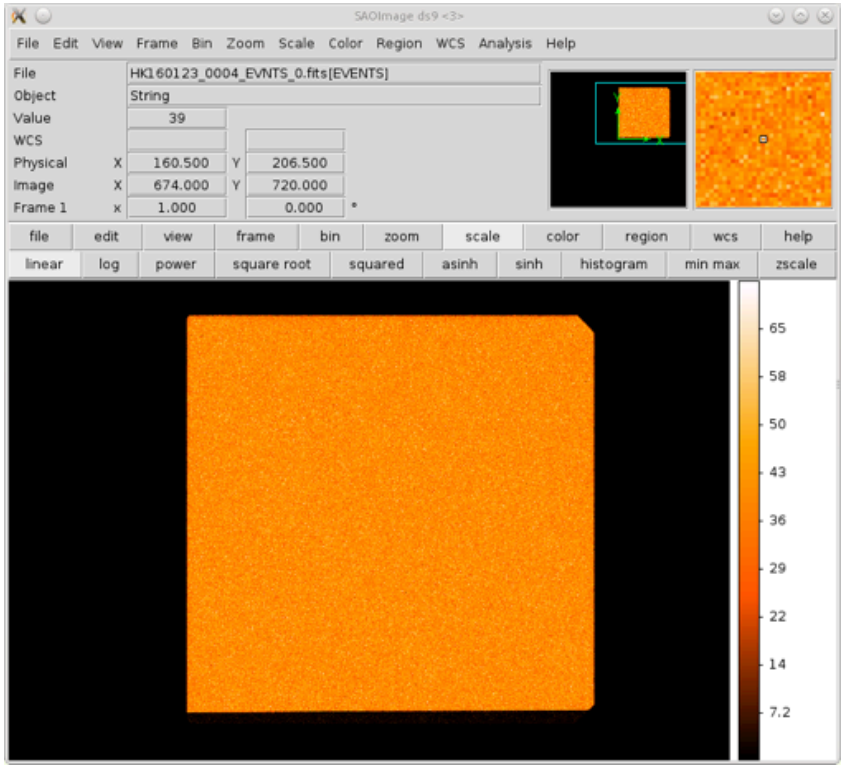


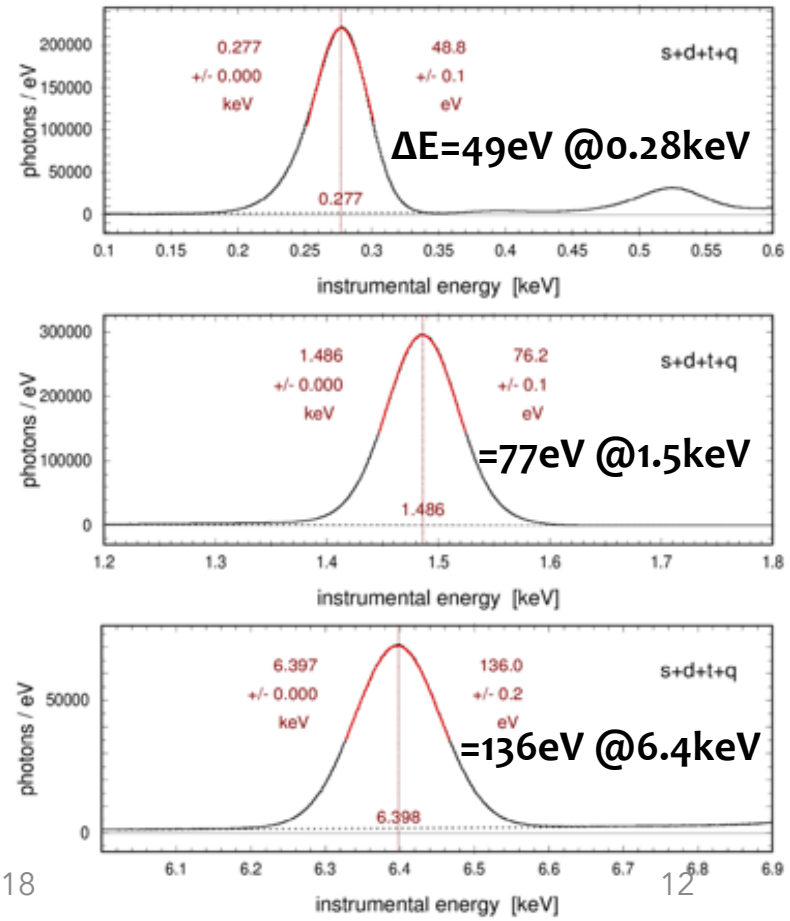


Meidinger et al, 9144E..1WM

Cameras Calibration

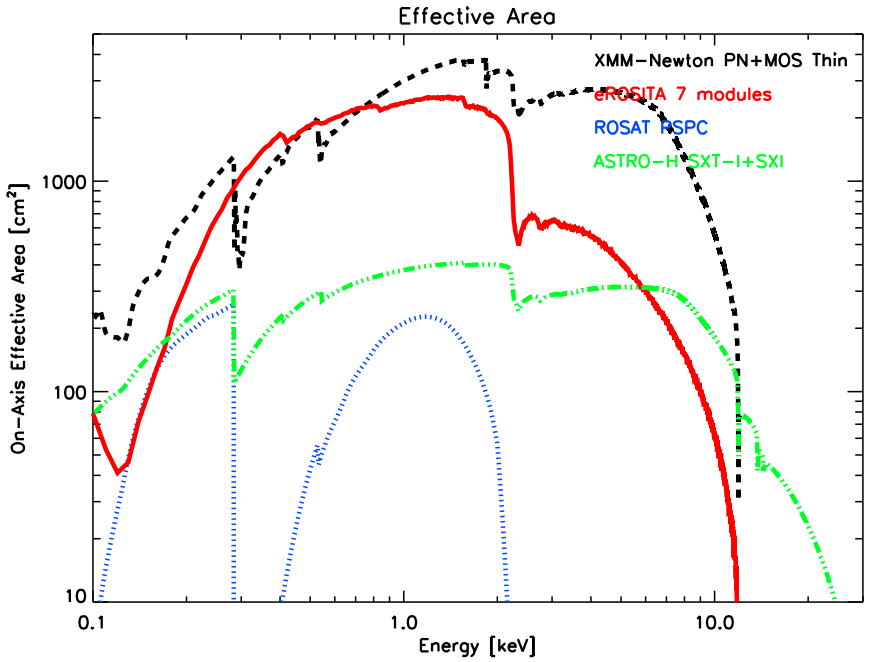
- **3.3 Billion** calibrated events! (K. Dennerl, N. Meidinger)
- **Spectral resolution** at all measured energies within specs (**R~20 @1.5keV**)
- Extremely **good uniformity**
- Only weak dependence on CCD and electronics temperature (unlike XMM)
- Very accurate absolute energy reconstruction (<0.06%)

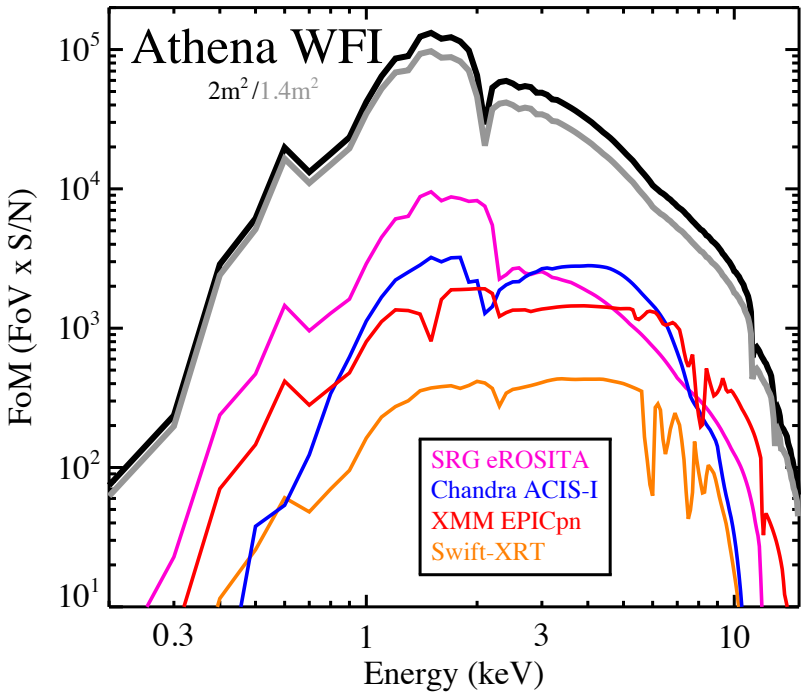




Effective Area and Grasp

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

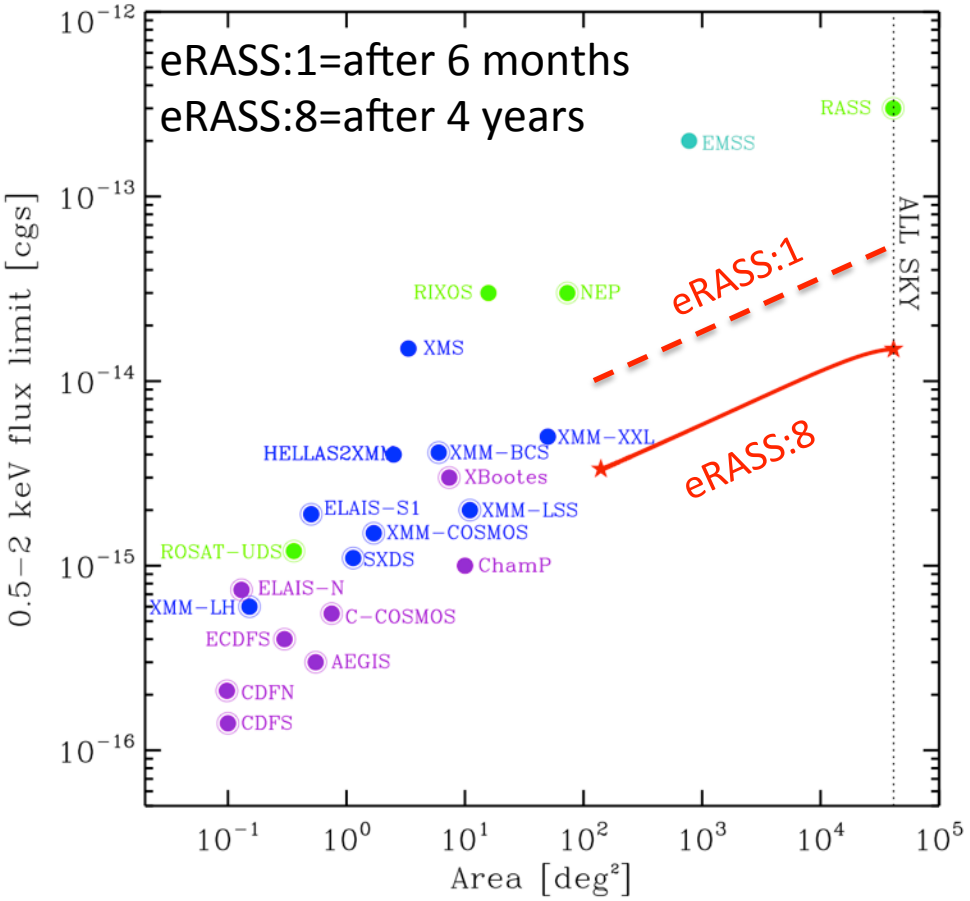




- Effective area at 1keV comparable with XMM-Newton
- Factor ~7-8 larger surveying speed (and 4 years dedicated to all sky survey)
- Survey FoM≈A_{eff}*FoV/(θ*Bkgn) (courtesy of Wik & Horsheimer)

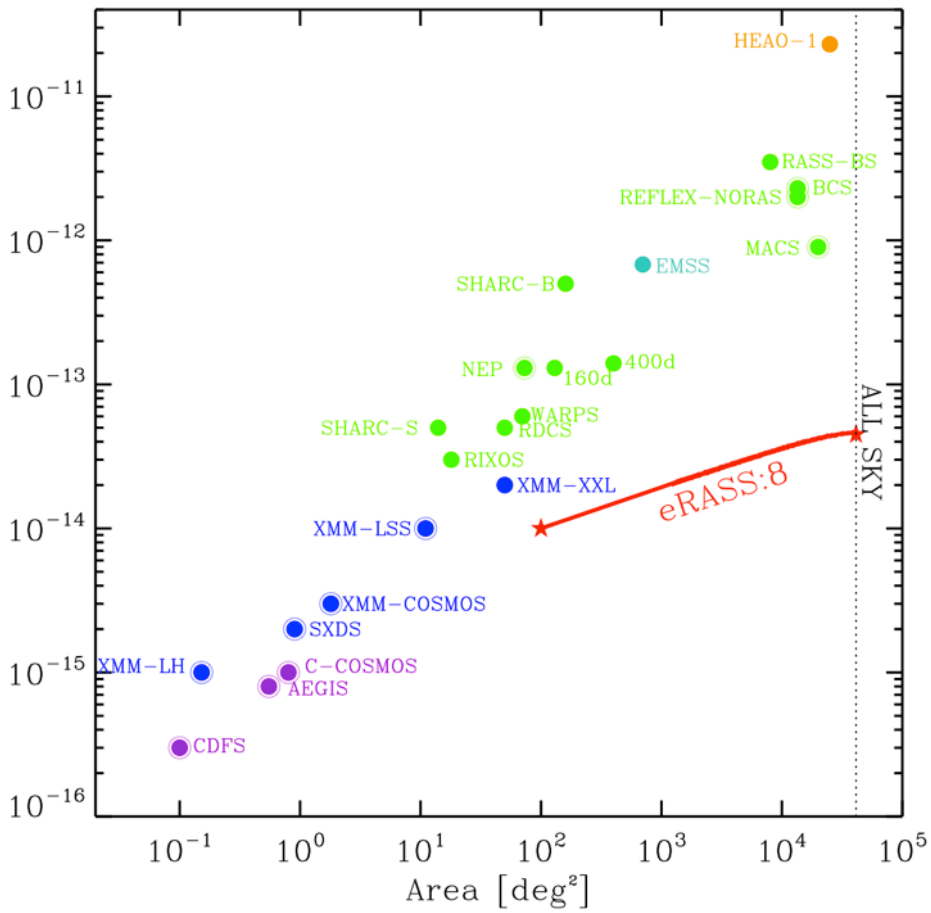
eROSITA surveys in context

Point sources sensitivity



All sky: 10^{-14} (0.5-2 keV)
2×10^{-13} (2-10 keV) [erg/cm²/s]

Extended sources sensitivity

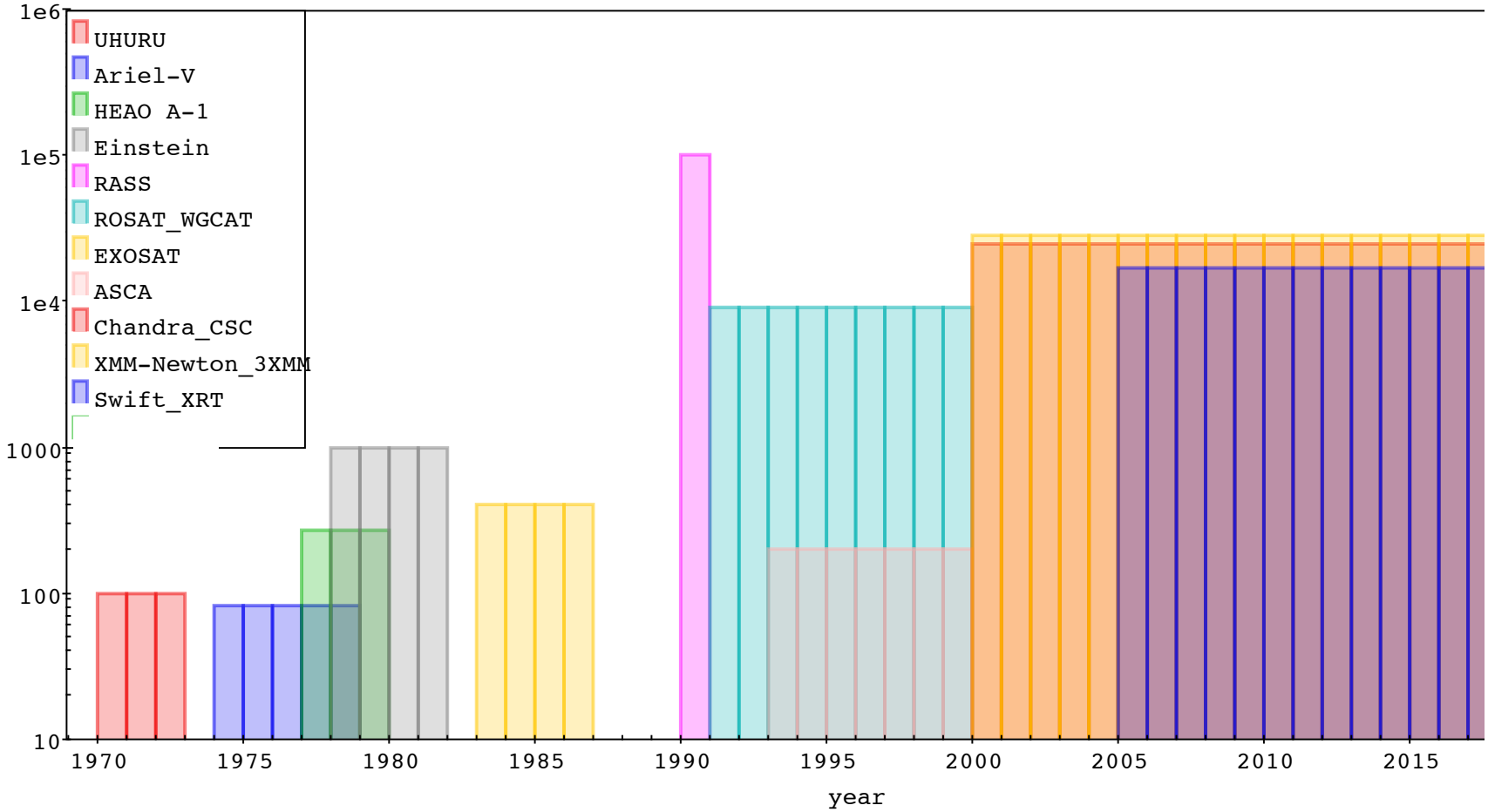


All sky: 3.4 x 10^{-14} (0.5-2 keV)

Merloni et al. 2012

eROSITA catalogs in context

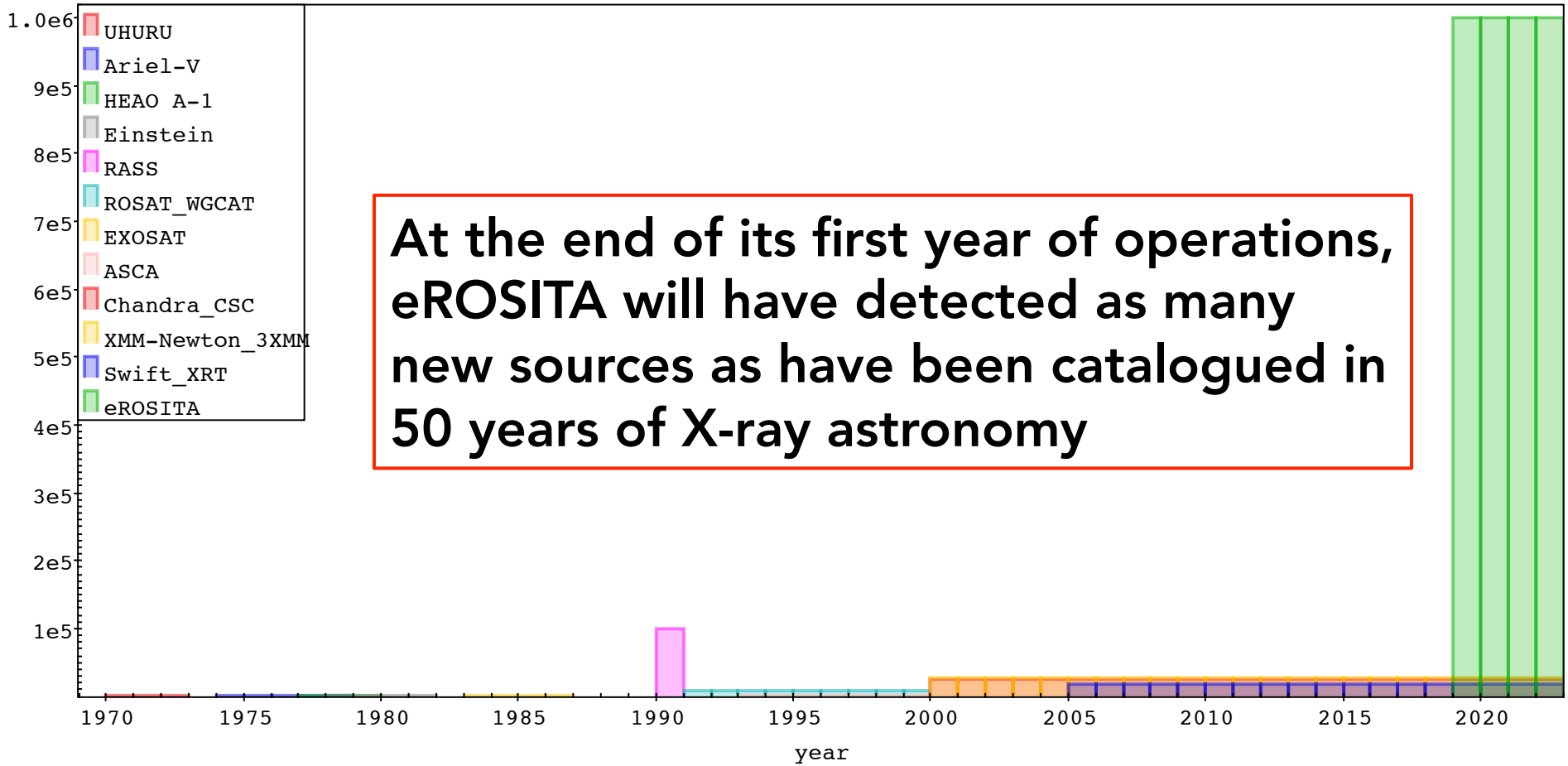
Logarithmic scale!



Approx. Number of X-ray sources detected per year (from published catalogs, not corrected for duplications)

eROSITA catalogs in context

Linear scale!

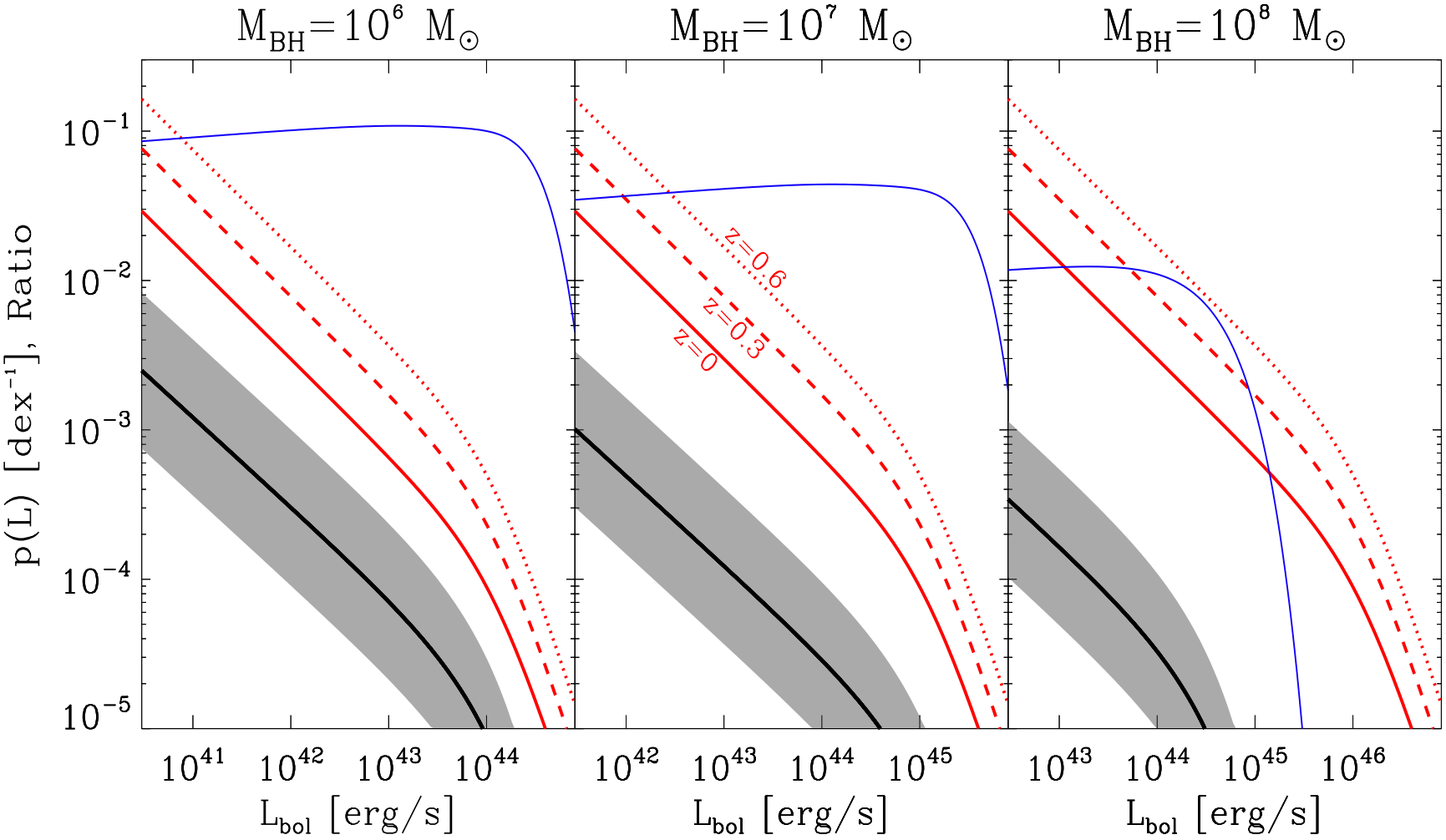


At the end of its first year of operations, eROSITA will have detected as many new sources as have been catalogued in 50 years of X-ray astronomy

eROSITA Legacy

- Detect ALL clusters more massive than 2-3x10^{14} $M_{\odot}$ (see e.g Borm et al. 2014; Clerc et al. 2018)
- Detect about 3M AGN (<z>~1; <log Lx>~44), probing SMBH growth over a wide redshift range (including 1000s of z>3 QSOs)
- 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…

TDE vs AGN duty cycles

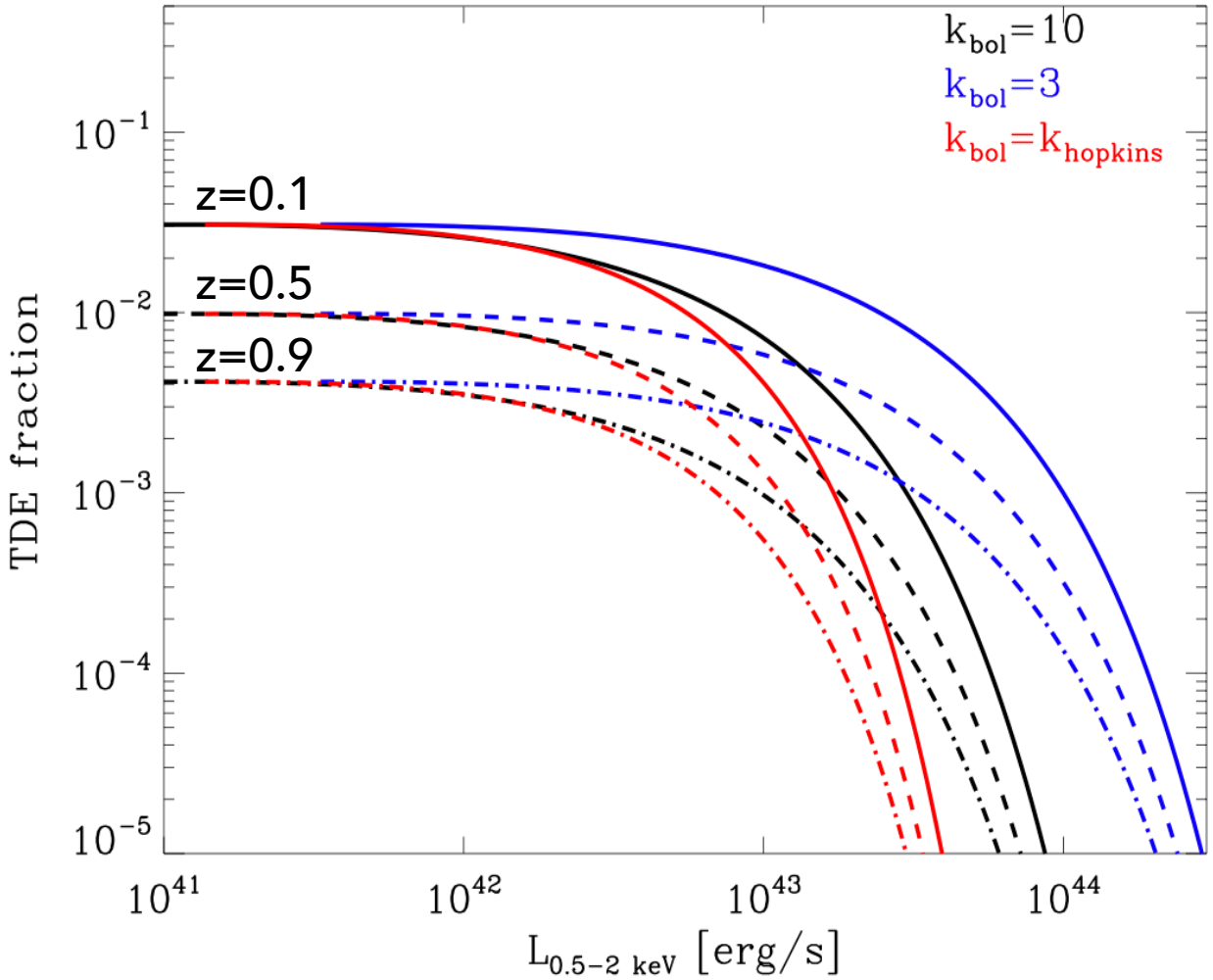


Red lines: AGN

Black lines: TDE

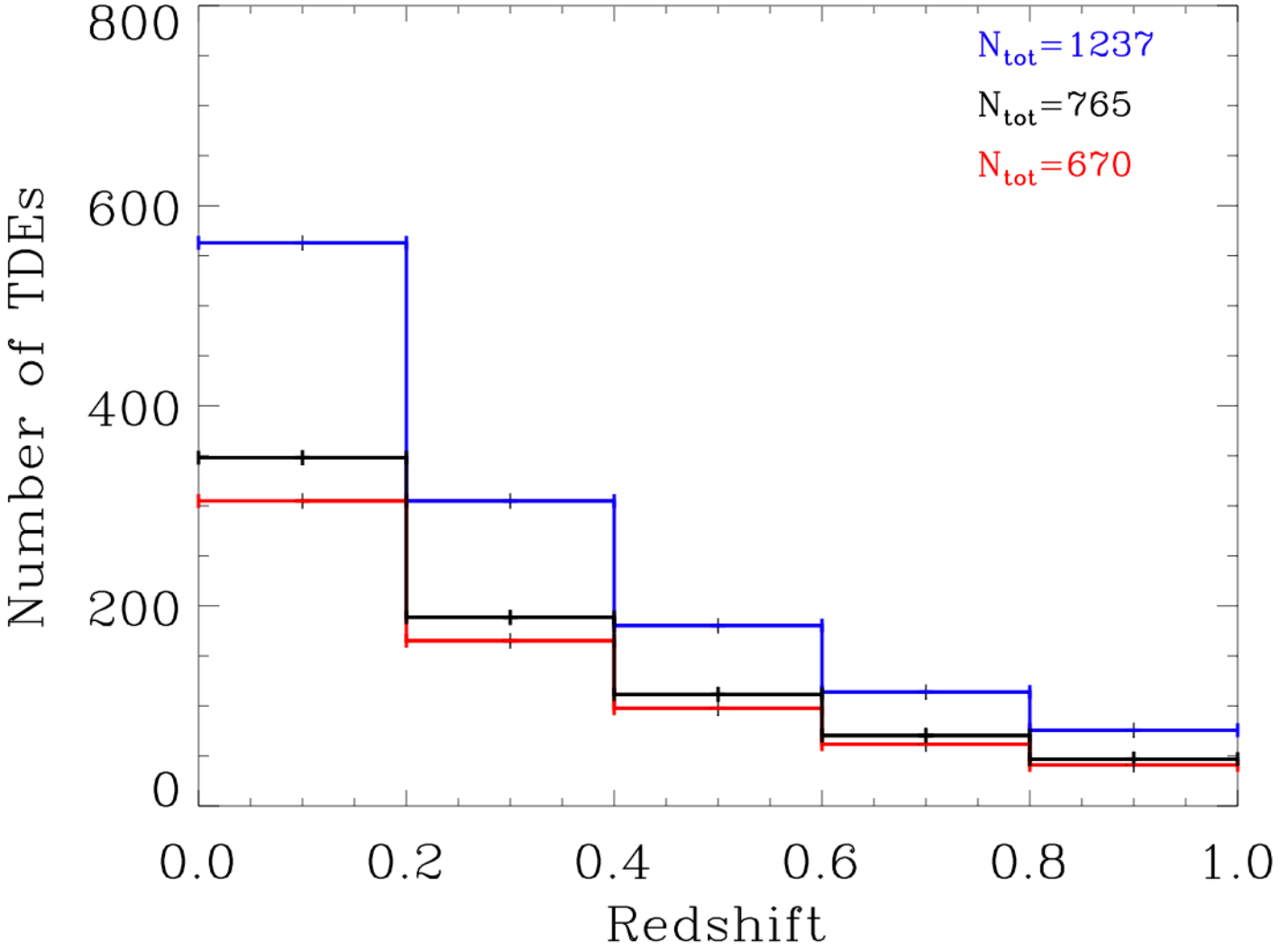
Merloni et al. 2015

TDE Fraction at soft X-rays



A few % of nuclear sources with (Log L_X<43) might be TDE!

>100 TDEs per month...



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

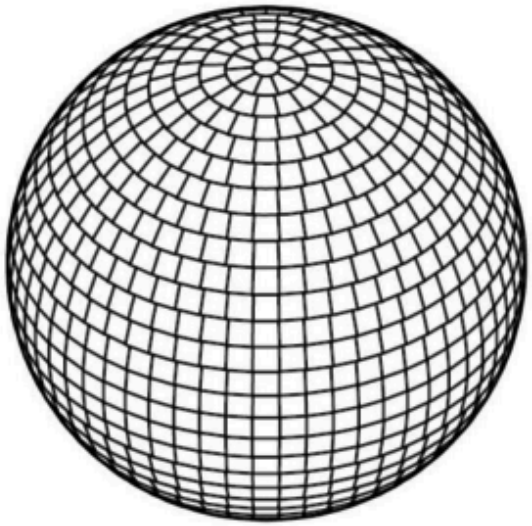
Spectroscopic follow-up

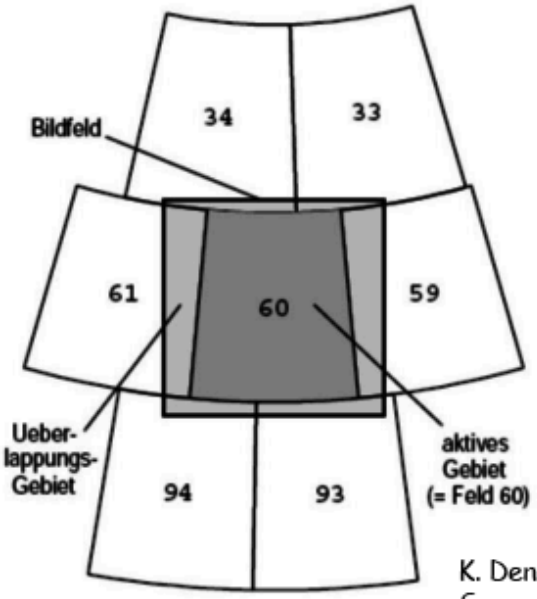
- **SDSS-IV/SPIDERS**
  - Systematic followup of all RASS and XXMSL point sources in eBOSS footprint (17<r<22.5, >85% completeness; 10k RASS and 1200 new XMMSL spectra)
  - Multi-object spectroscopy of faint clusters (CODEX sample; Nicolas' talk)
- **SDSS-V (2020-2024)** www.sdss.org/future/
  - SDSS + 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
  - 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)

The SASS pipeline processes all-sky survey and pointed data:

All-sky survey:

- Sky is divided into 5839 equatorial equal-area fields of approx. 3°x3°
- After event-calibration, incoming data stream is split and accumulated in same number of overlapping 3.6°x3.6° fields, centred on each of these fields (local, parallel projection sky maps)
- Source detection and further source-level analysis is performed on these sky maps





K. Dennerl,
Survey II Concept

Pointed observations:

- Incoming data stream is split in different pointings (←timeline)
- Source detection is performed on 1.6°x1.6° fields, centred on pointing

Content of source catalogs

RA
DEC
RADEC_ERR
LII
BII
EXT
EXT_ERR
EXT_LIKE
ML_RADIUS
ID_CLUSTER
MASKFRAC

n=0,4
DET_LIKE_n
RATE_n
RATE_ERR_n
FLUX_n
FLUX_ERR_n
ML_CTS_n
ML_EFF_n
ML_BKG_n
ML_EXP_n
VIGNET_n
n=1,3
HR_n
HR_ERR_n

APE_CTS
APE_EFF
APE_BKG
APE_EXP
APE_RADIUS
APE_POIS

Wavelet (Alexis)?

detUID
souUID
IAUNAM
TMIN
TMAX
NEW
UNIQUE
SRC_CAND
n=1,9
SRC_CAND_n
DIST_NN
SRC_DENS

QUALITY
QF

MEAN_RATE
MEAN_ERROR
SIGMA_RMS
TIME_MIN
TIME_MAX
RATE_MON
RATE_MAX
RATE_MIN_ERR
RATE_MAX_ERR

NH
NH_U
NH_L
PHOTON
PHOTON_U
PHOTON_H
NORM
NORM_U
NORM_L

ERMLDET | APETOOL | CATPREP

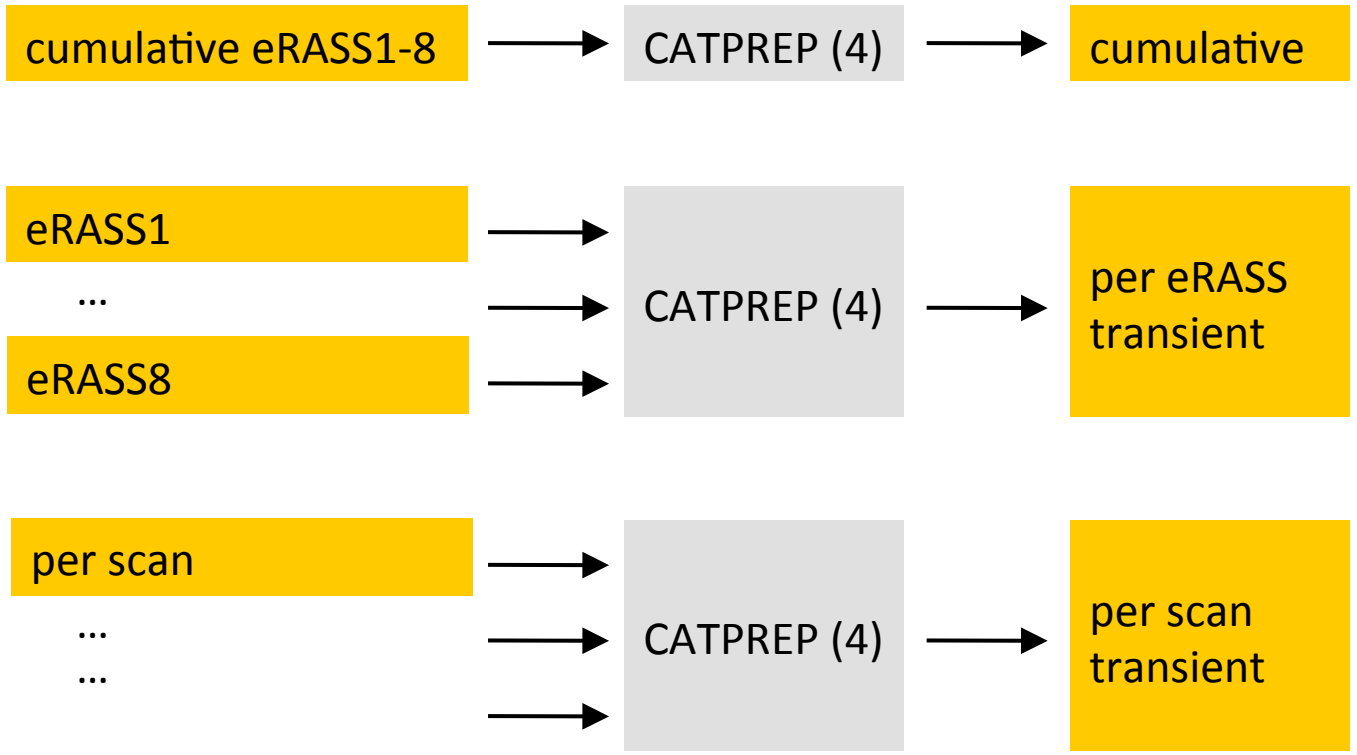
DPVAL | VARICHCK | SPECFIT

eSASS pipeline catalogs & transient catalogs

CATPREP (4) – merging of source catalogs

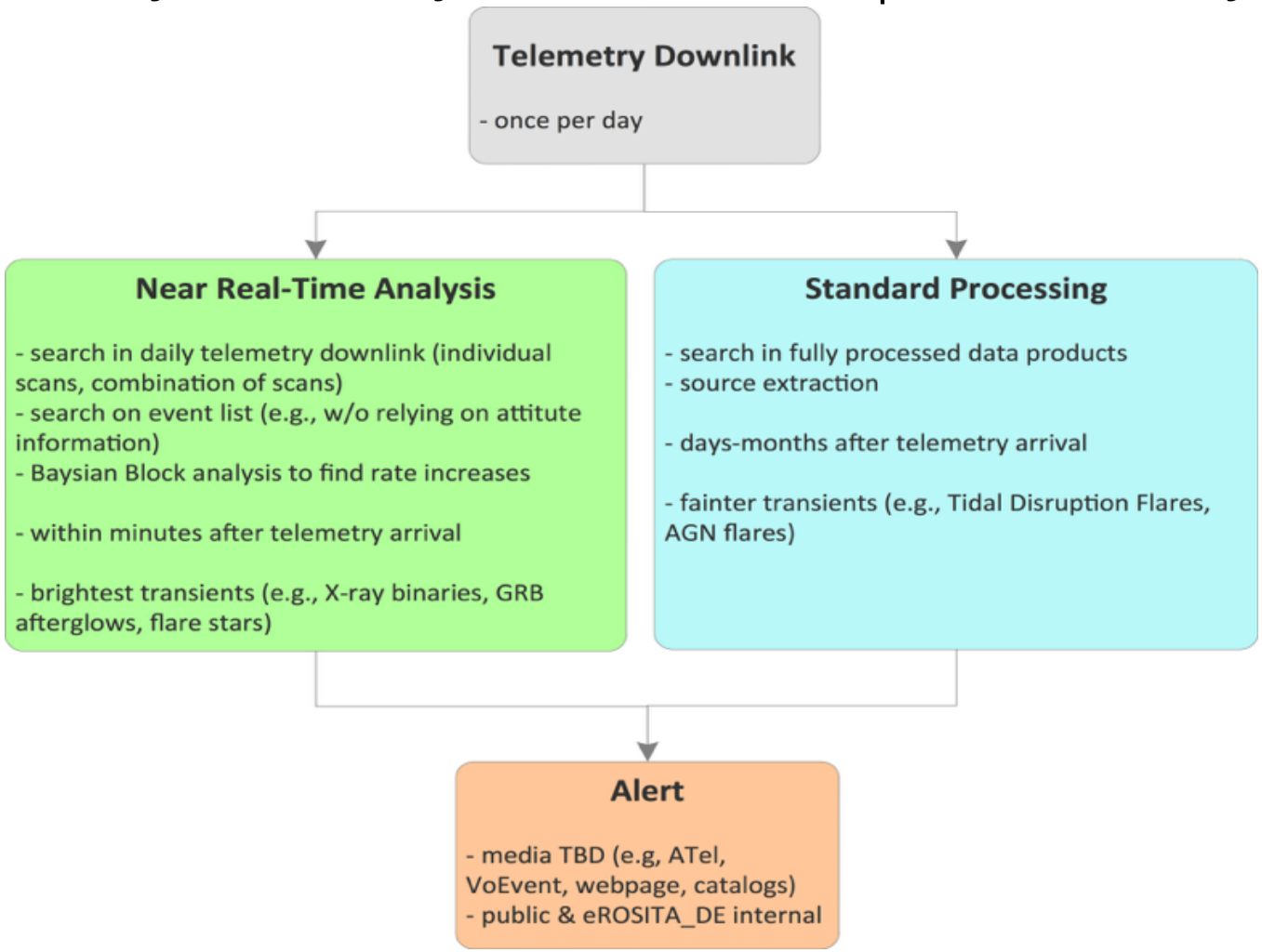
single sky field catalogs

all sky/DE hemisphere



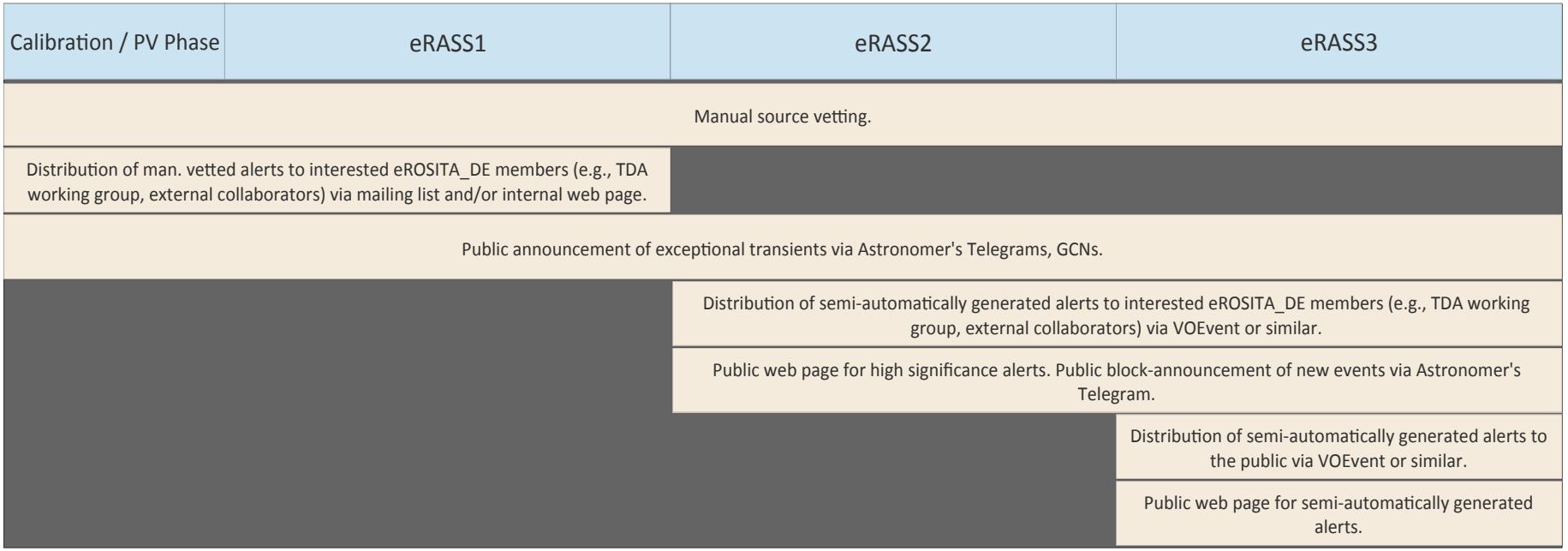
Transients and alerts

Transients and variables will be searched for in all time scales, from <30s to years. (Only in the German part of the sky!)



Transients and alerts

Initially alerts will be vetted manually and available only to the eROSITA_DE community. Once operation is stable and reliable, distribution to the wider community is foreseen through TBD means (ATel, VoEvent, web, …).



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 yrs, 3 releases (‘21, ‘23, ‘25; 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 (German Consortium):**
  - Individual External Collaborations (proposal to WGs)
  - Group External Collaborations (team-to-team MoUs)

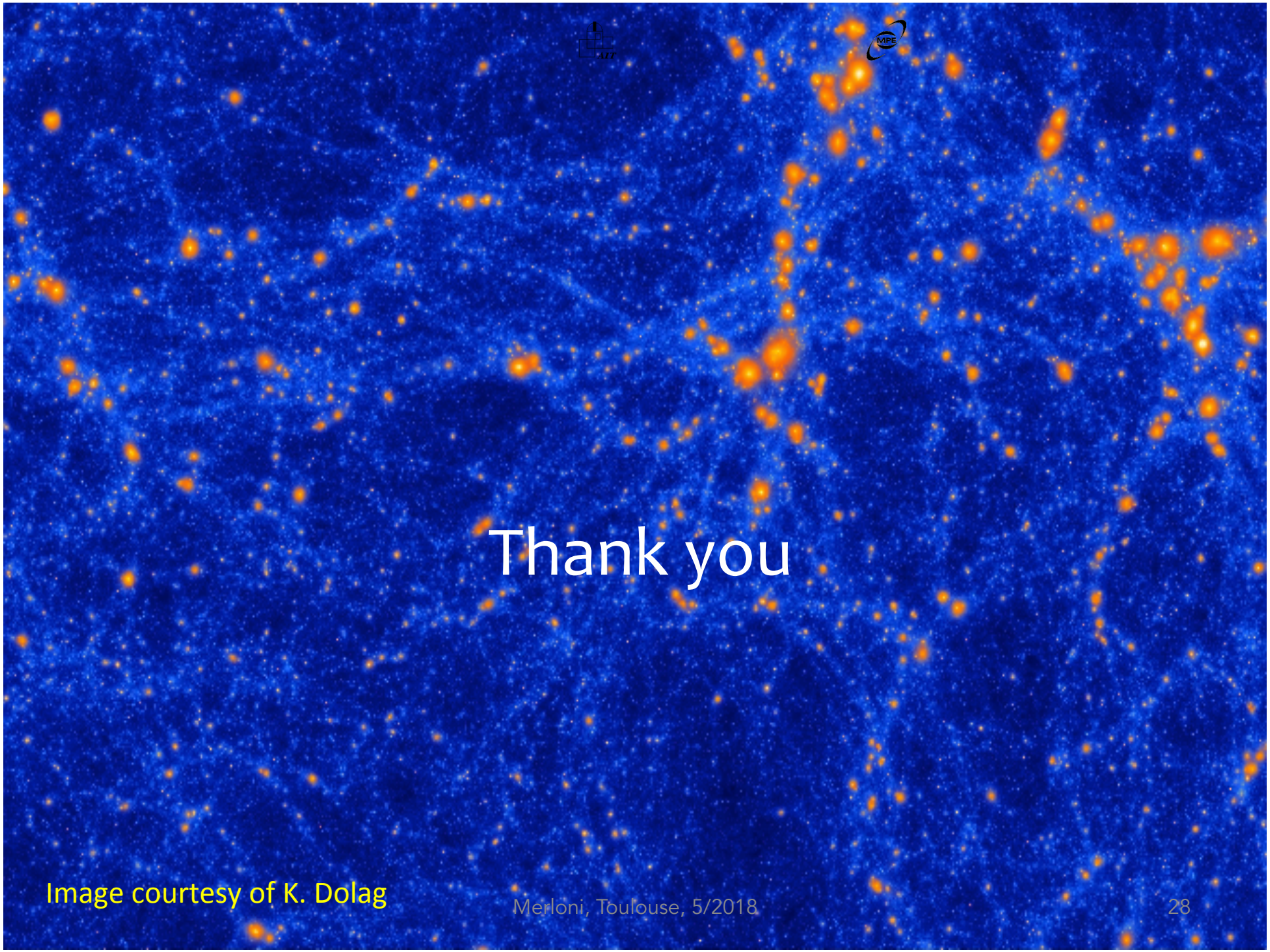


Image courtesy of K. Dolag