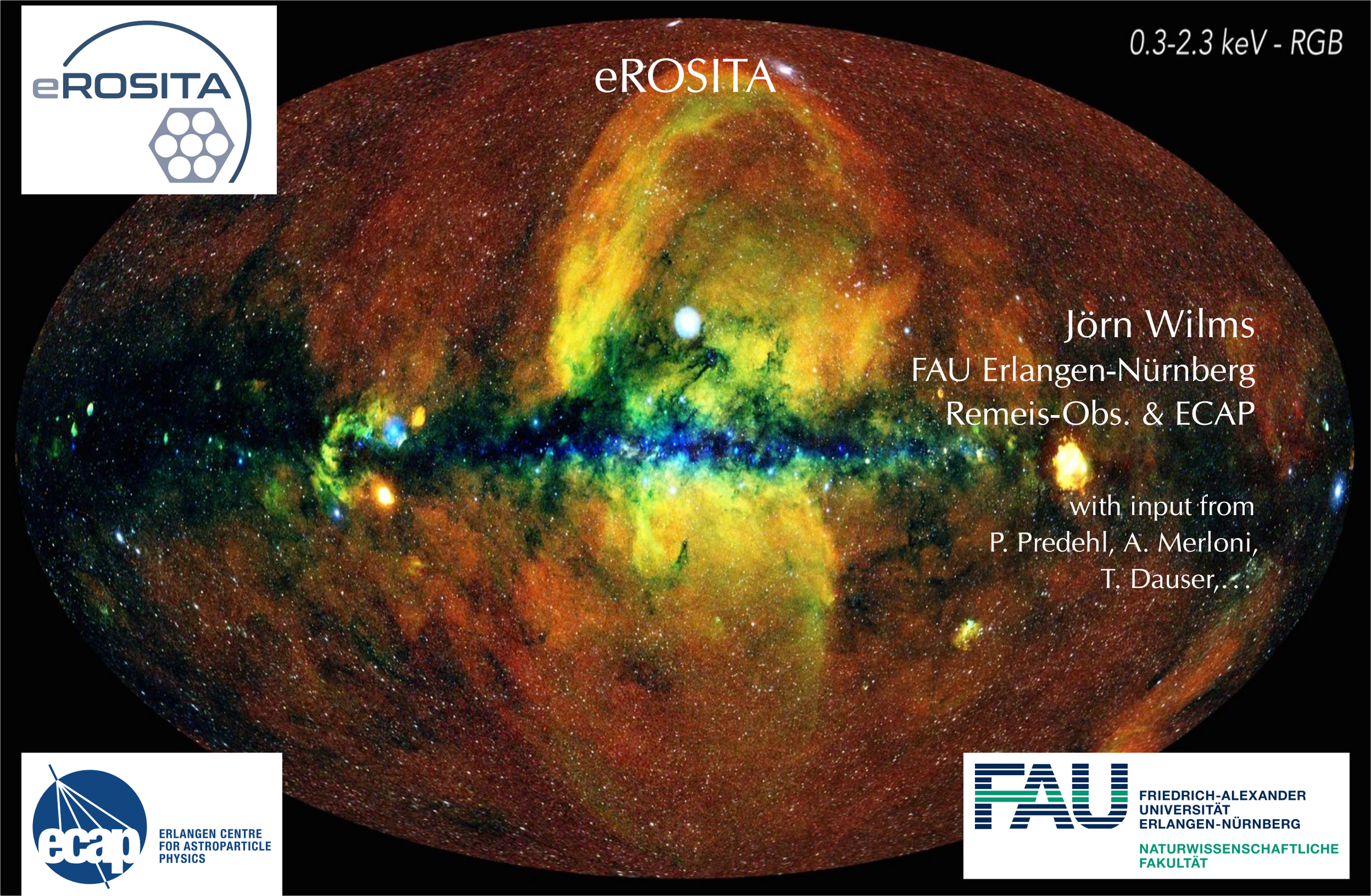


eROSITA

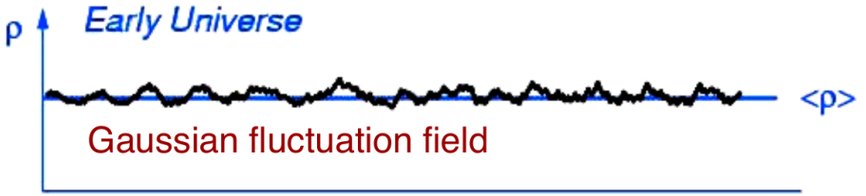
Jörn Wilms
FAU Erlangen-Nürnberg
Remeis-Obs. & ECAP

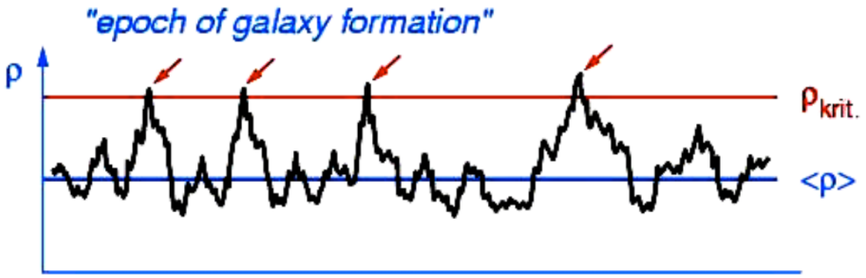
with input from
P. Predehl, A. Merloni,
T. Dauser,...

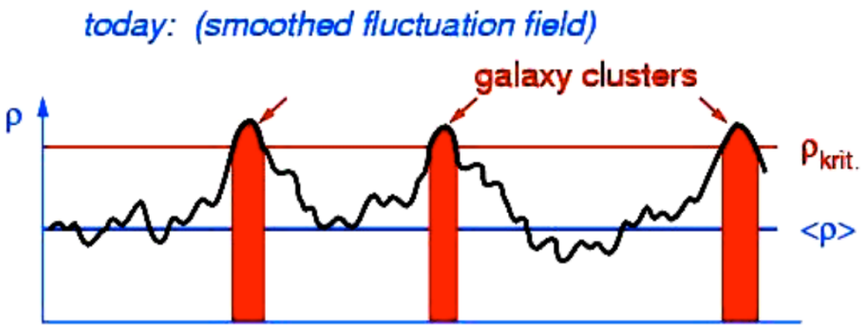
ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE
FAKULTÄT

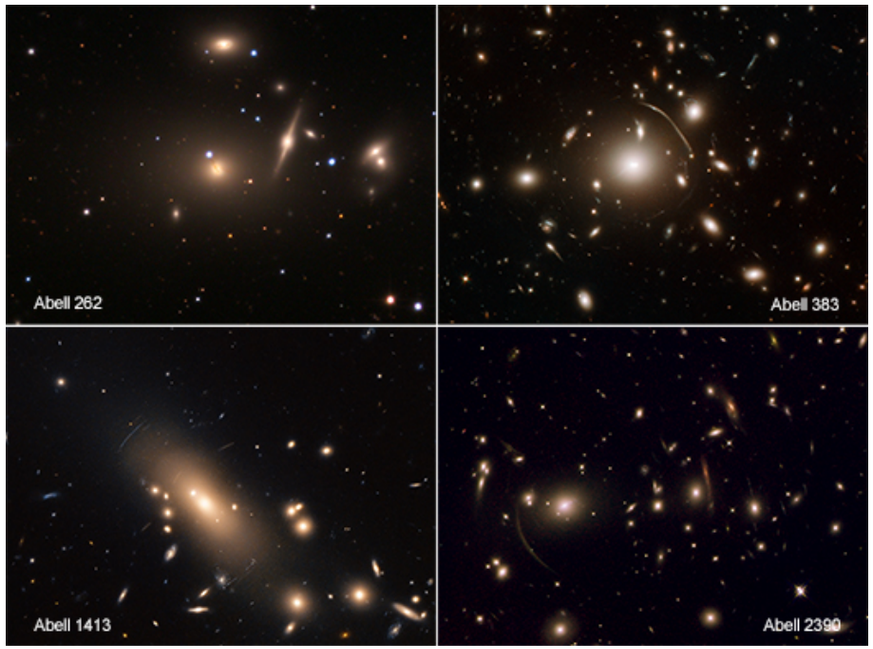
Structure Formation







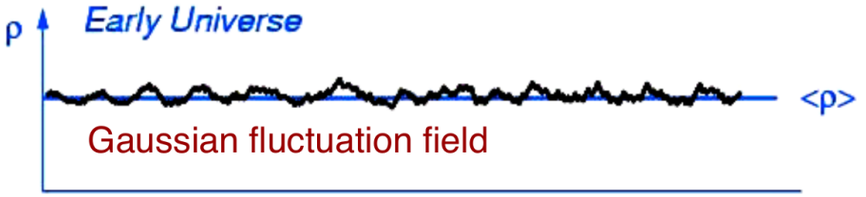
mass of galaxy clusters ~ 10^{14} – 10^{15} M_{sun}

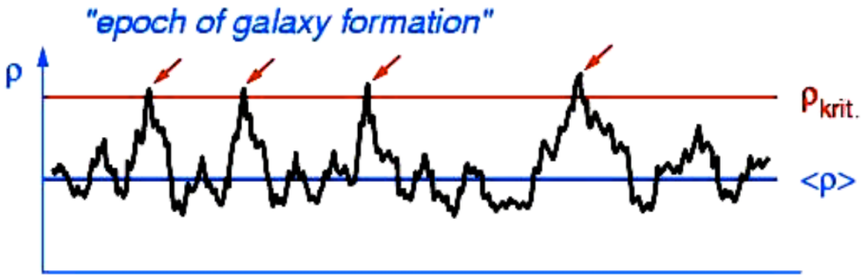


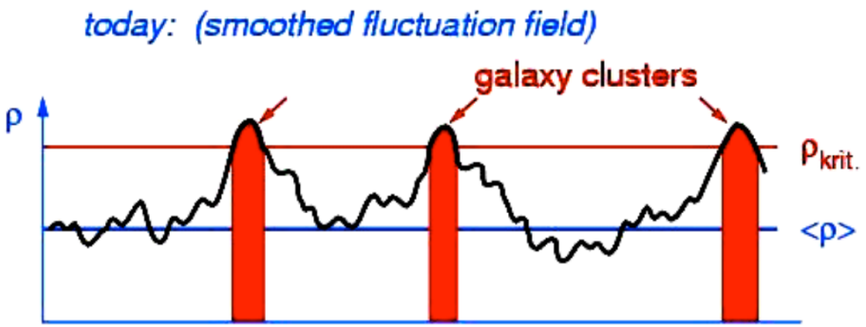
CXC

Formation and growth of galaxies and galaxy clusters since the Big Bang

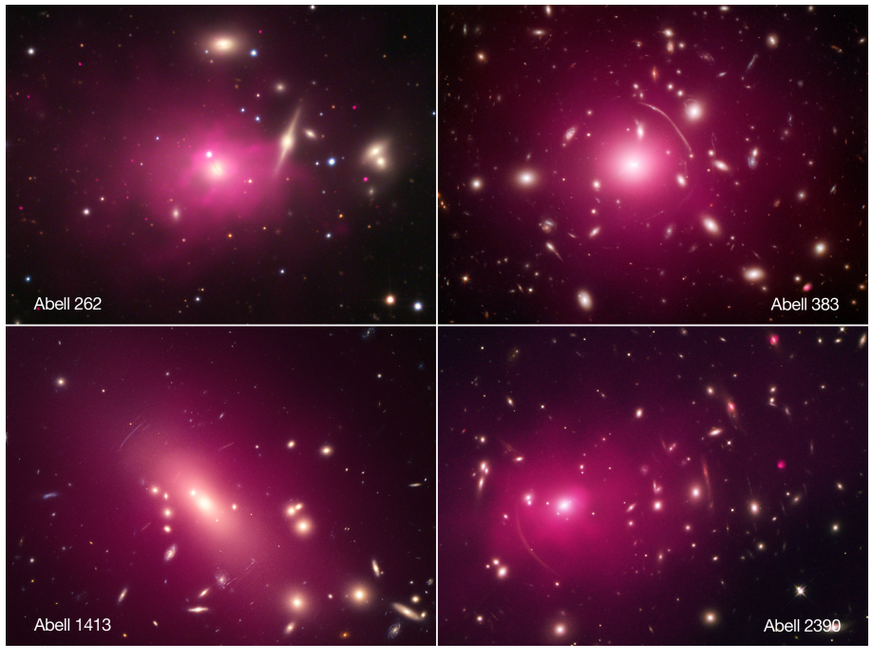
Structure Formation







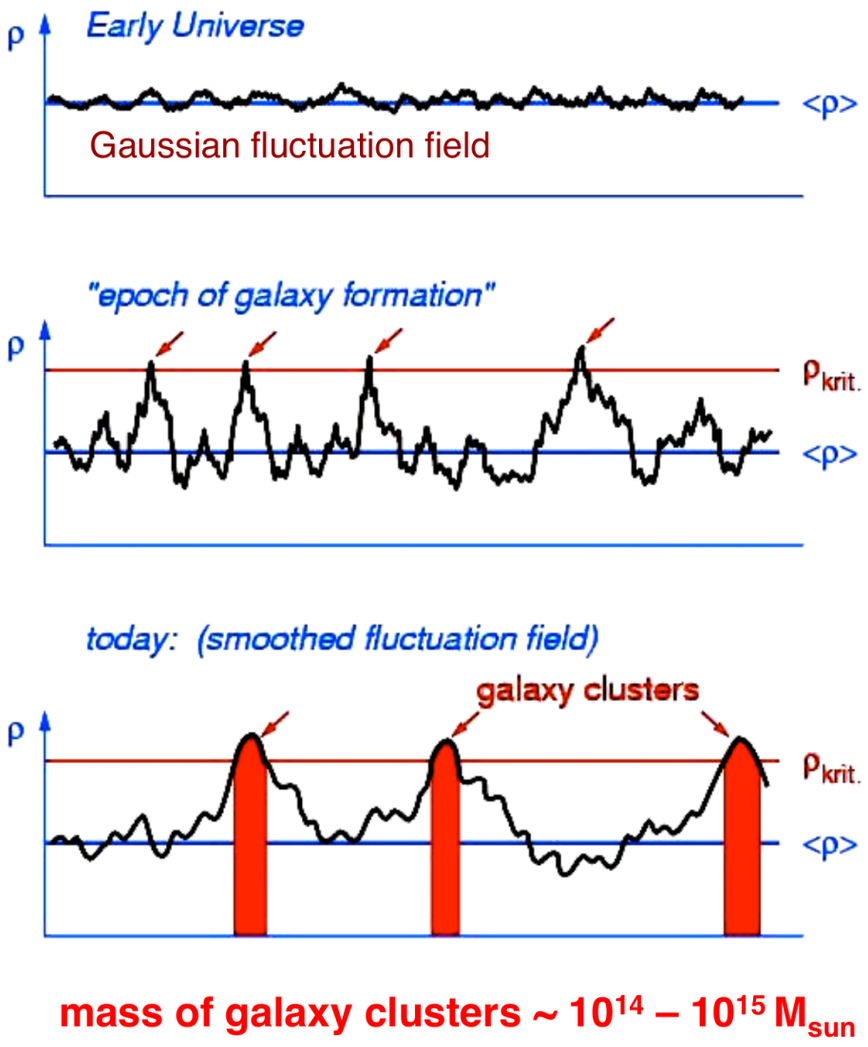
mass of galaxy clusters ~ 10^{14} – 10^{15} M_{sun}



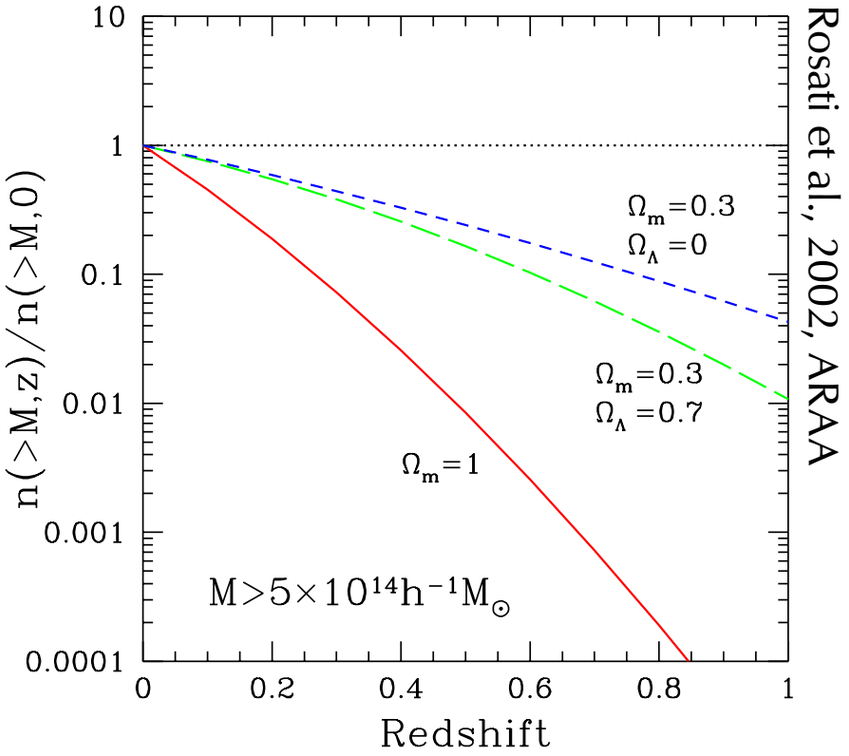
CXC

Formation and growth of galaxies and galaxy clusters since the Big Bang

Structure Formation

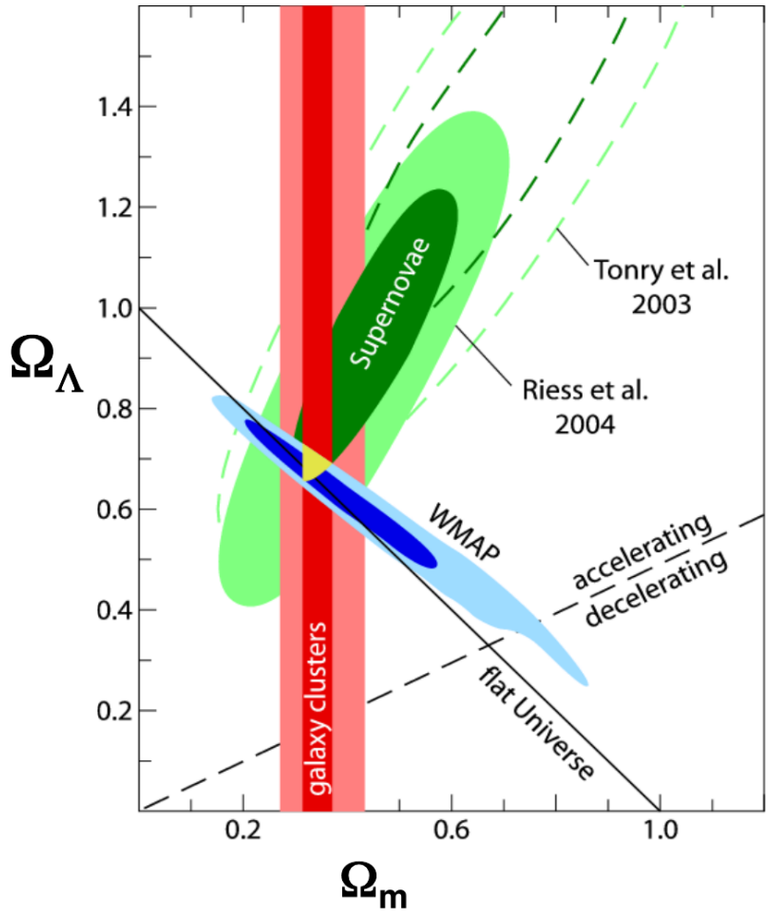


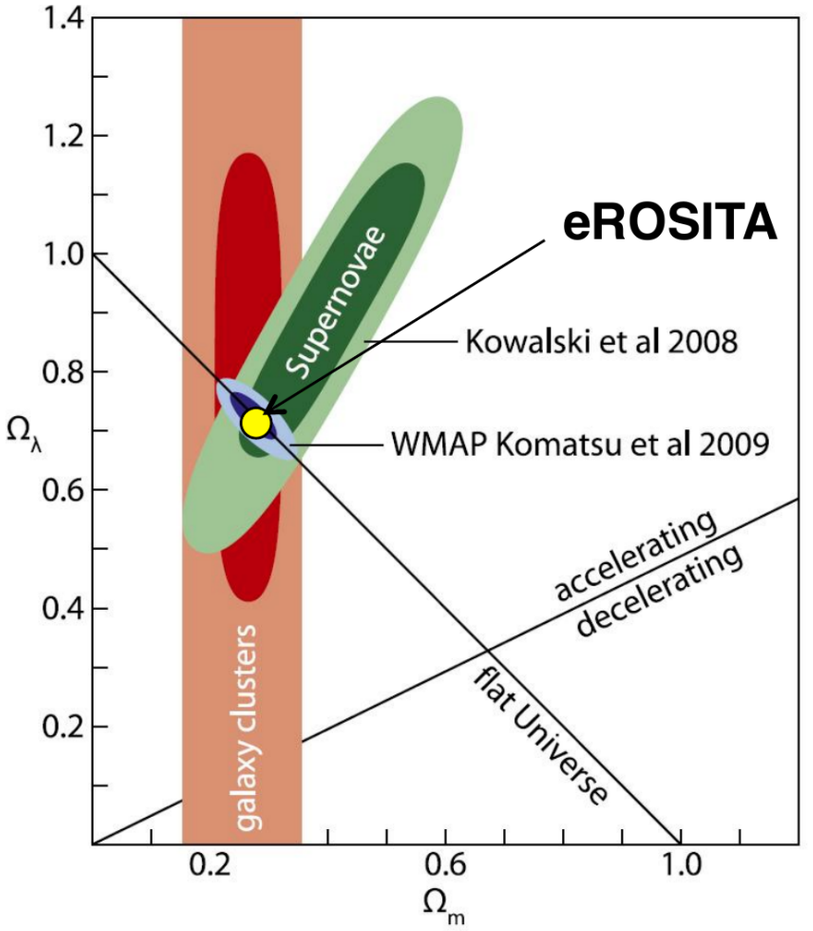
mass of galaxy clusters ~ 10^{14} – 10^{15} M_{sun}



Formation and growth of galaxies and galaxy clusters since the Big Bang

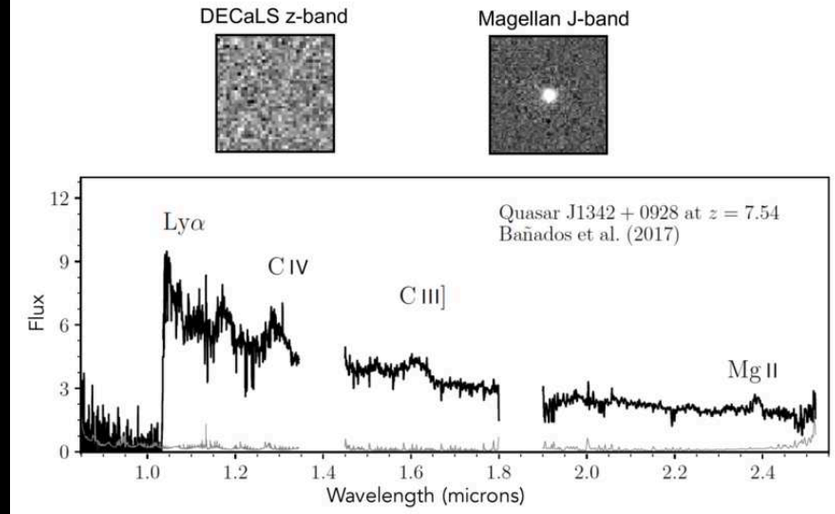
Structure Formation



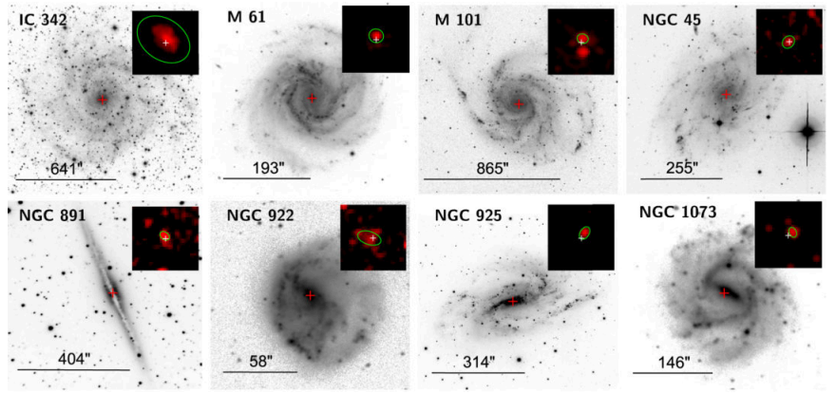


Böhringer

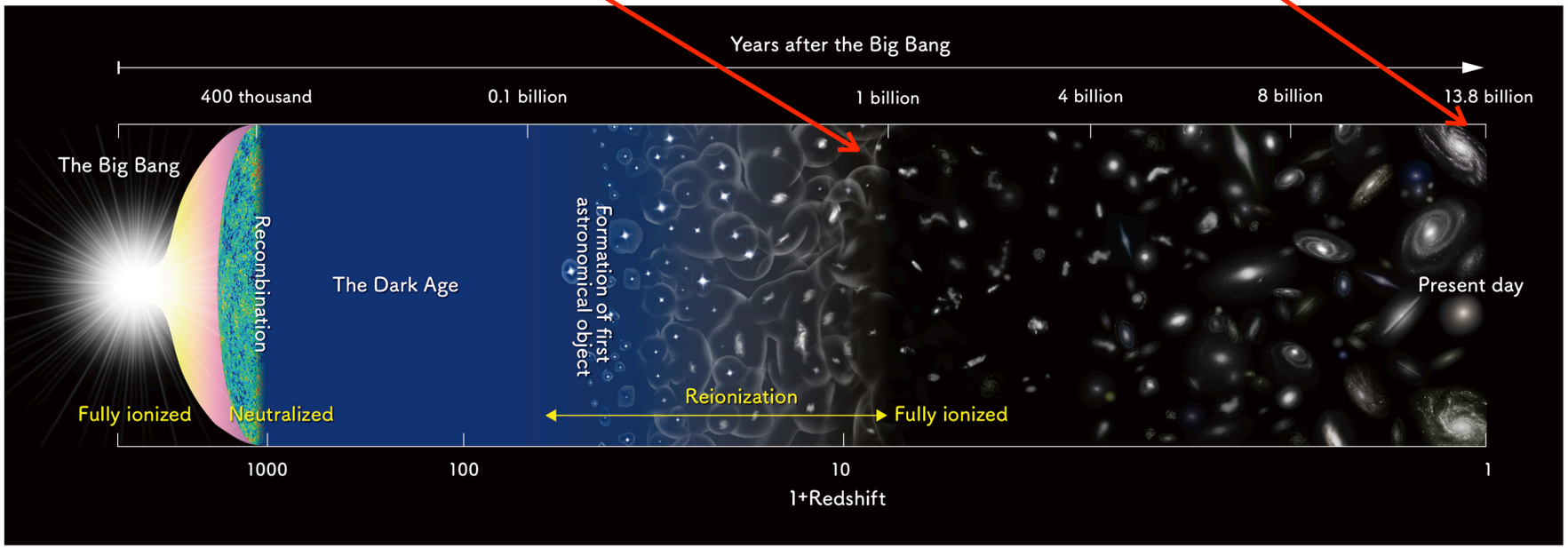
Galaxy clusters yield mass density, Ω_m, and energy density of "dark energy", Ω_Λ



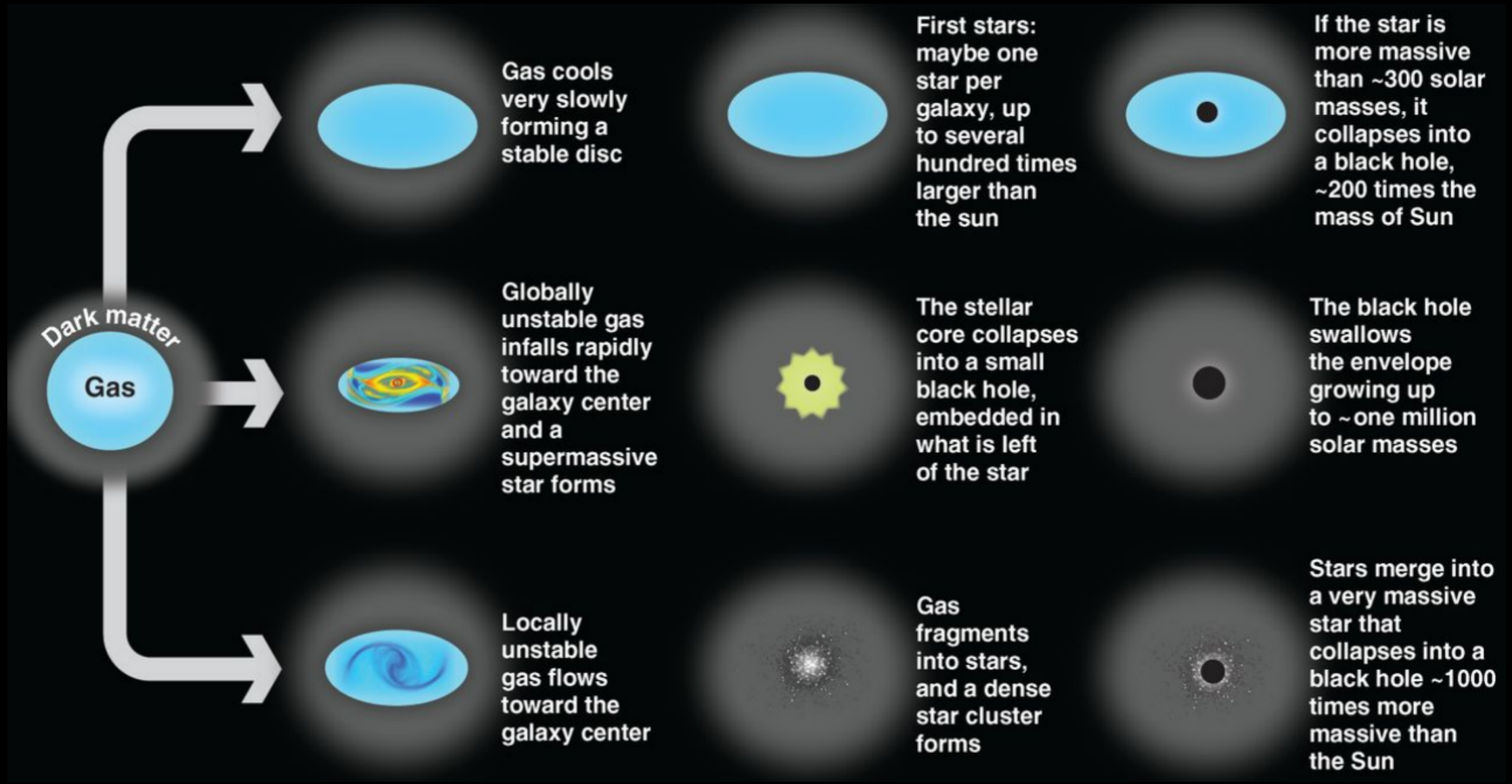
~10^6 — 10^9 $M_\odot$ Black Holes



$8x10^{11}$ $M_\odot$ Black Hole!



K. Holley-Bockelmann

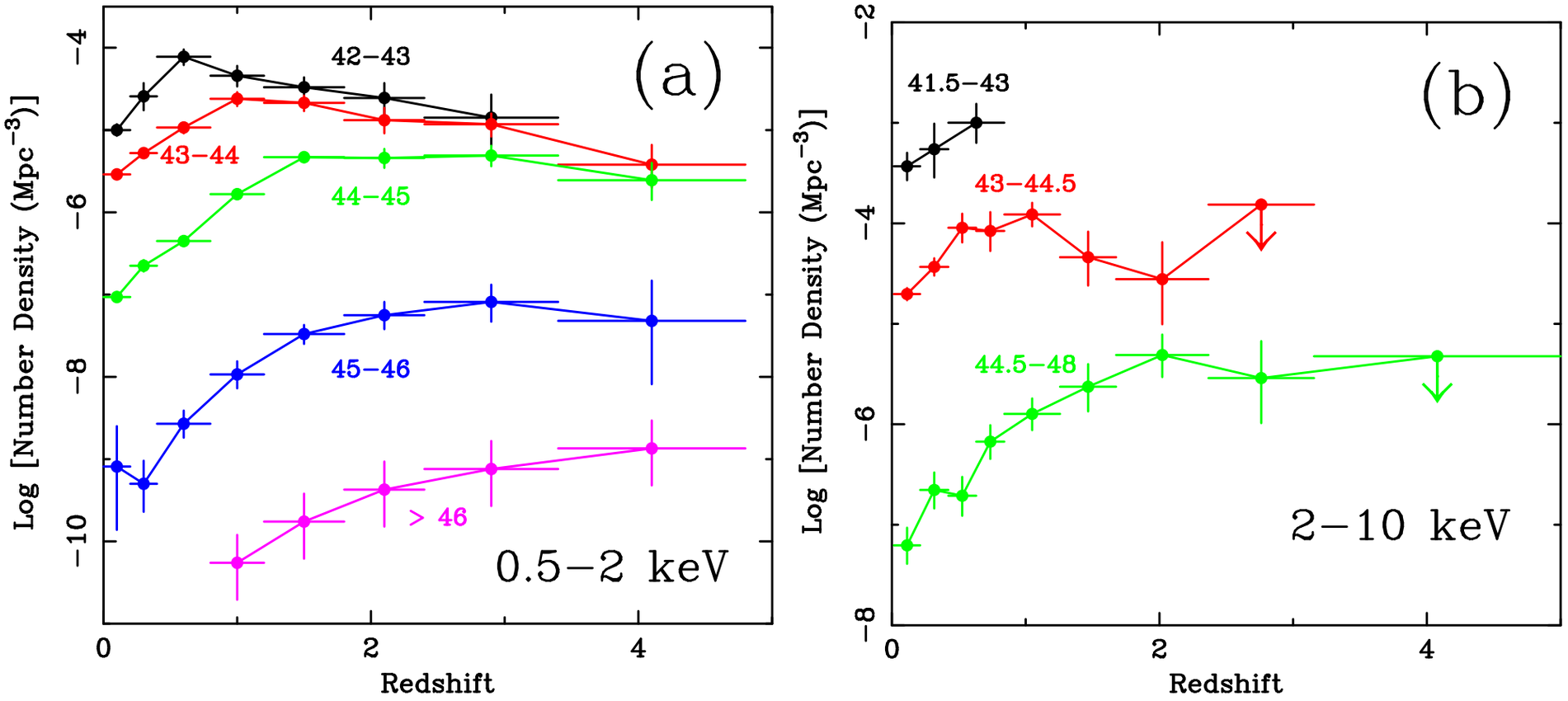


(Volonteri, 2012, Science 337, 544)

Evolution of Black Holes depends on

- type of accretion process
- interaction with surrounding galaxy (“Feedback”)

Active Galactic Nuclei



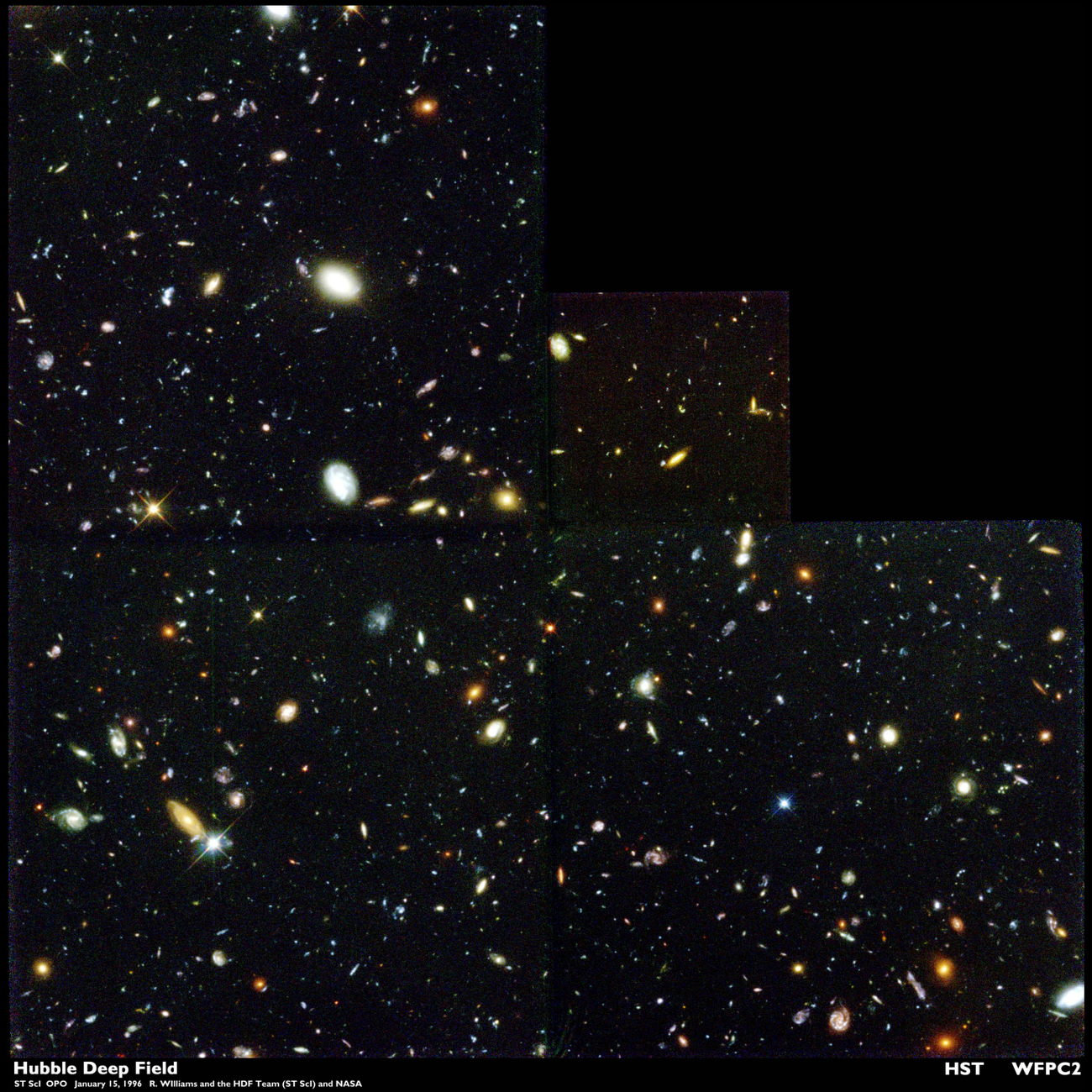
(Brandt & Hasinger, 2005)

Existing X-ray data: Luminosity Evolution

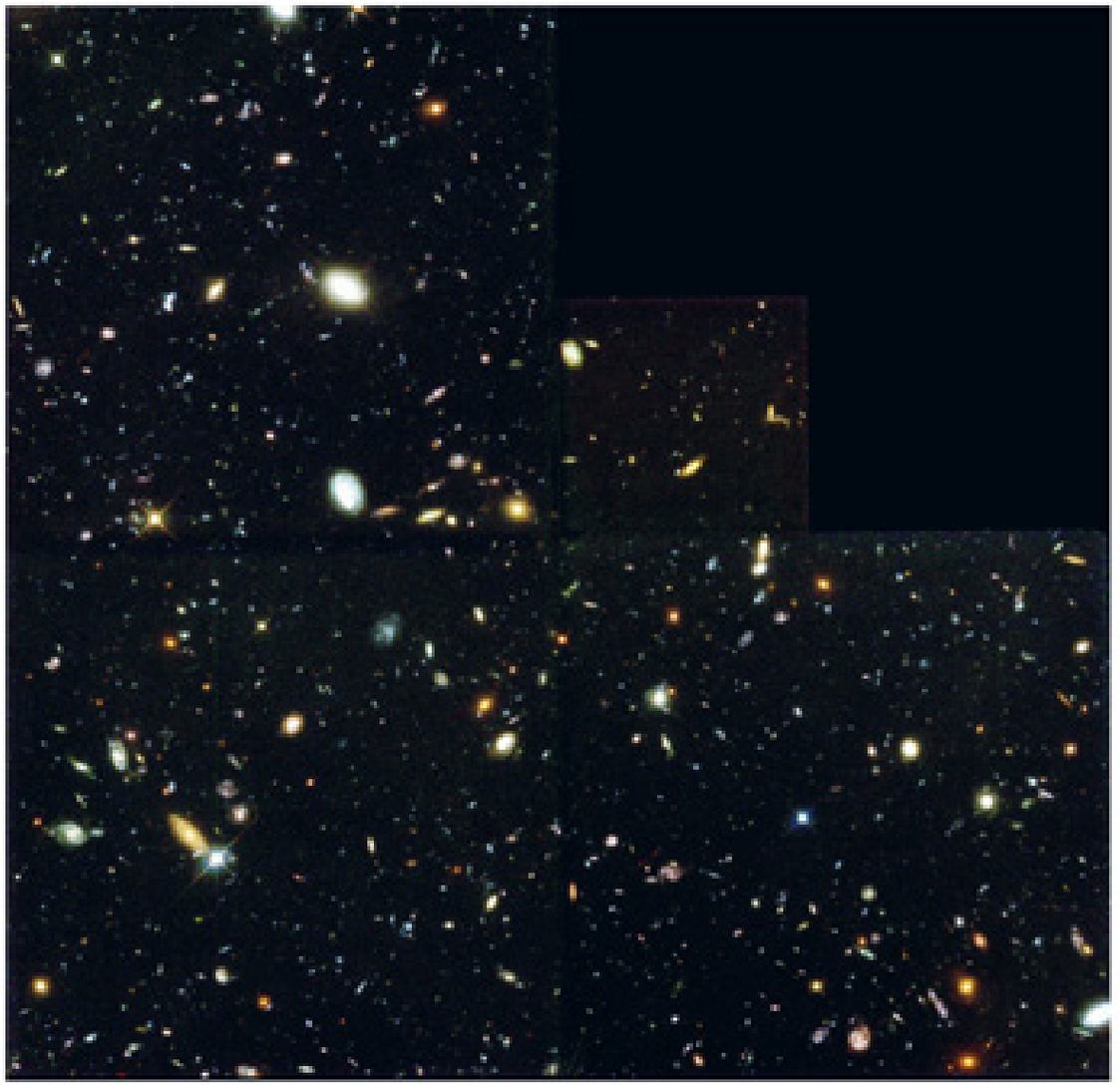
- Space density of AGN: lower L_X for lower z
- (probably) less evolution at lower L_X

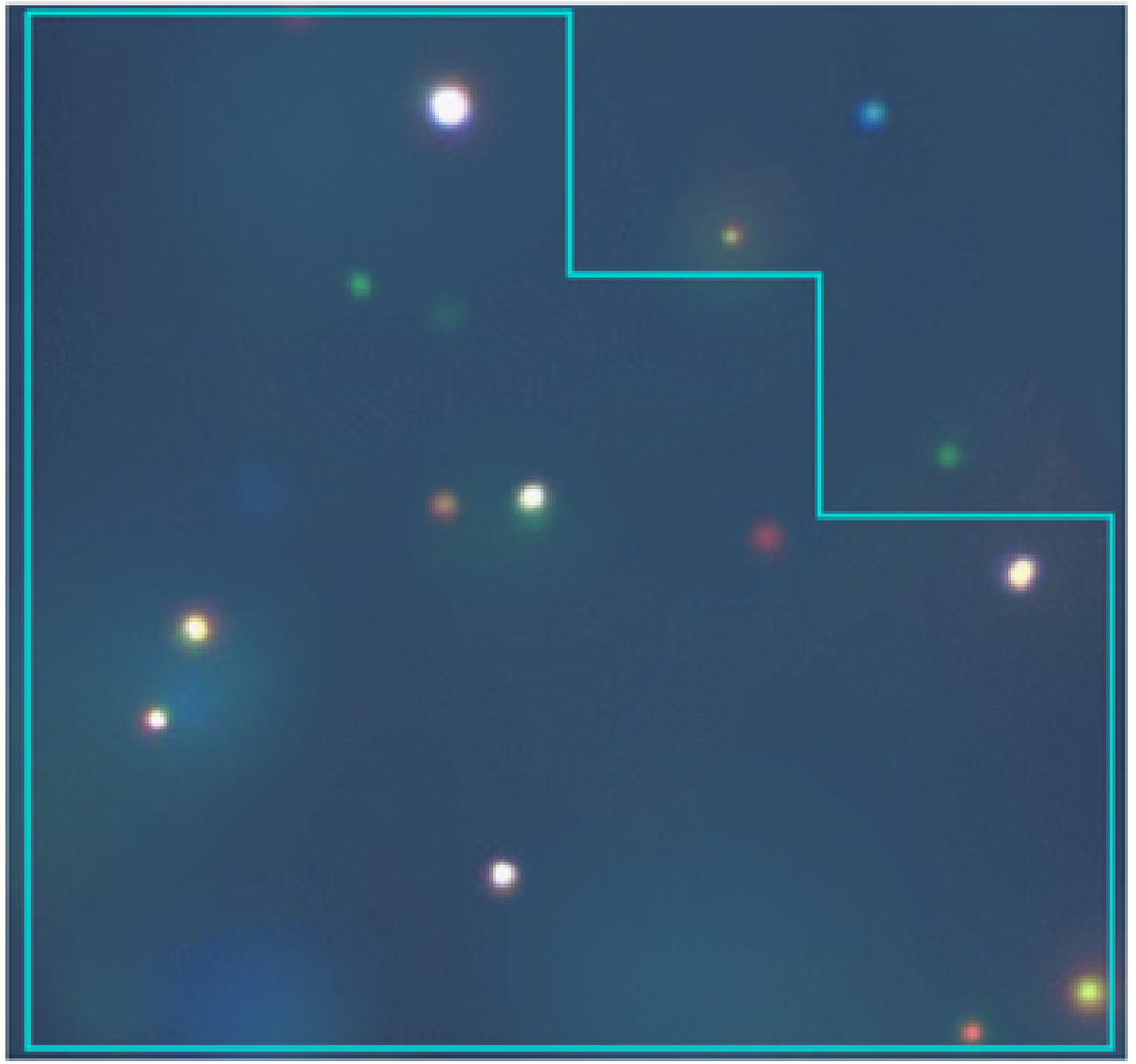
$\Longrightarrow$ If L_X depends on M_{BH}, then most massive BHs formed first ("anti-hierarchical AGN evolution")

Galaxy evolution in one picture



1995 December: Hubble Deep Field: 8 d exposure





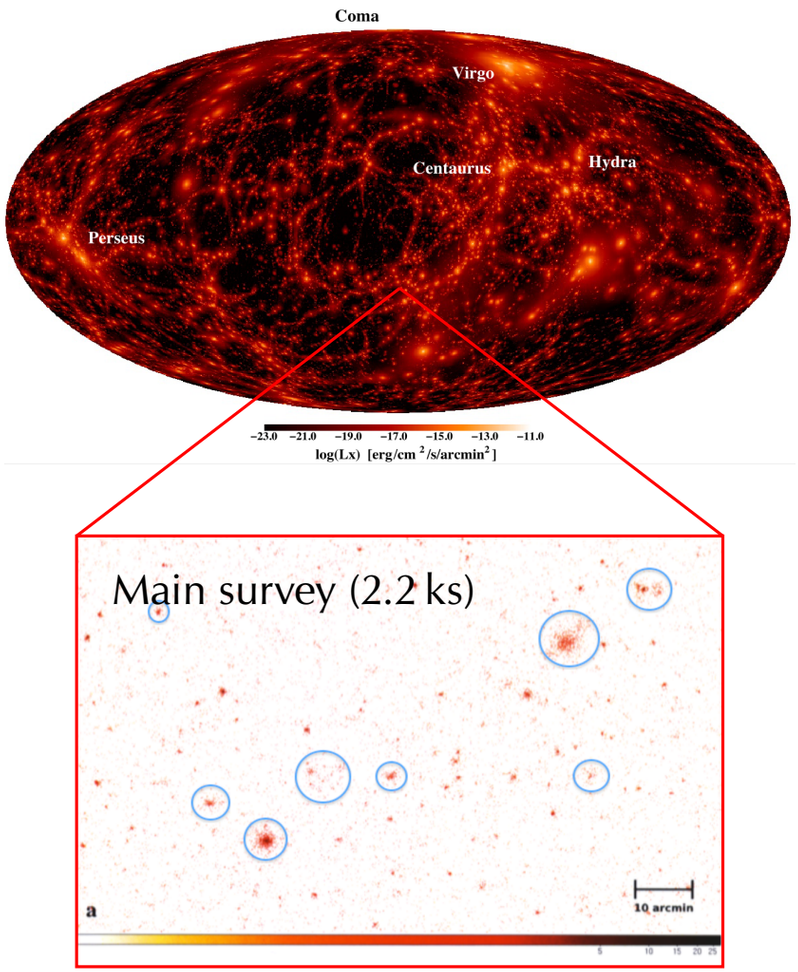
HST

Chandra

Chandra/HST Image of the Hubble Deep Field North; 500 ksec

Multiwavelength astronomy: X-rays best way to find accreting black holes

eROSITA at a glance



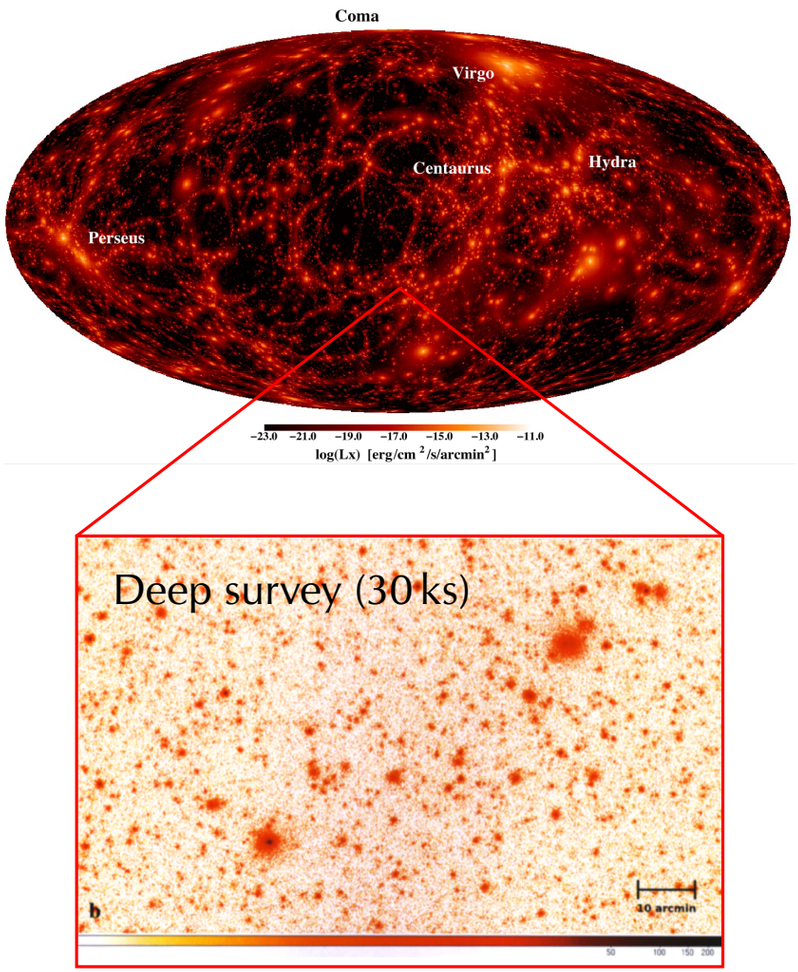
Main Goals:

- Search for Galaxy Clusters
  100000 clusters
- Evolution of black holes
  2×10^6 AGN

Strategy:

- sky survey
  down to 6×10^{-14} cgs
- deep survey
  ($\sim 100\,\square^\circ$) to 10^{-14} cgs
- 1° FoV, moderate spatial resolution
  ($< 28''$ on avg.)
- large collecting area
  ($>2000\,\mathrm{cm}^2$ at 1 keV)
- good spectral resolution
  155 eV 6.4 keV

eROSITA at a glance



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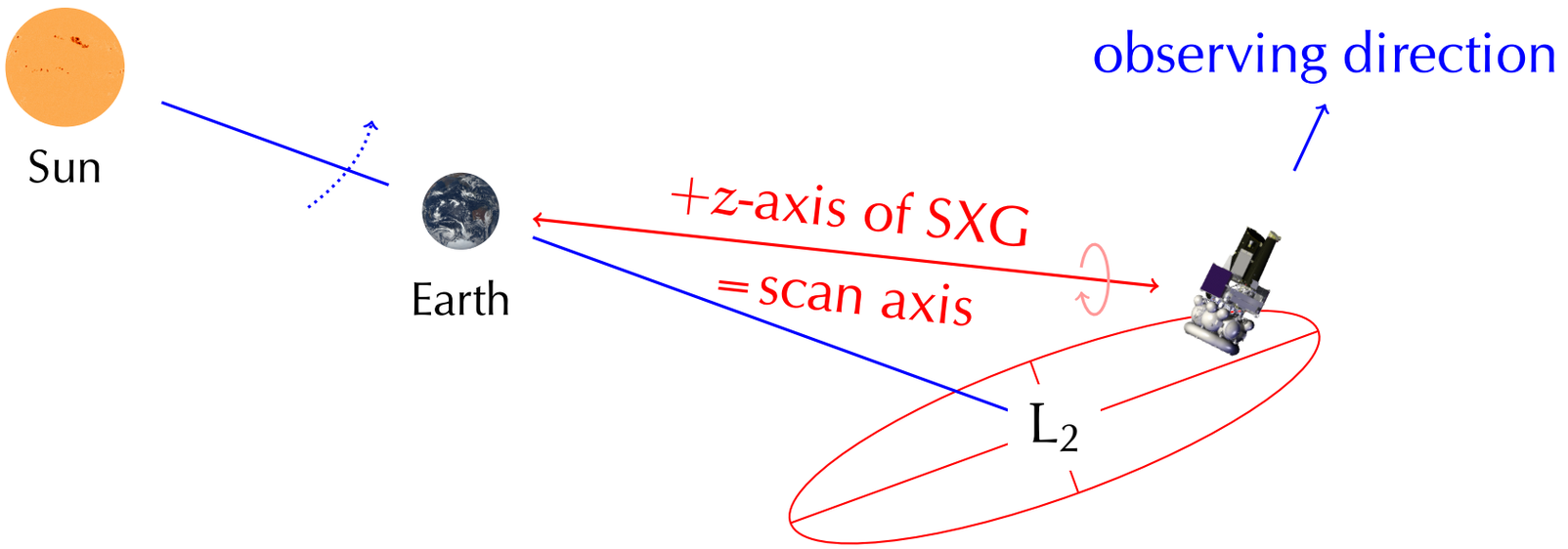
Survey design



Mission profile:

- L_2-Orbit (1.5 Mio km from Earth)
- scan axis points towards Earth (~4 h/rotation)

4 years survey
3 years pointing
(w/o effects of Russian aggression in Ukraine)

eROSITA on Spektr-RG

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


Andrea Merloni (MPE)
(starting 9/7/20)


Rashid Sunyaev (IKI)


Kirpal Nandra (MPE)

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

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

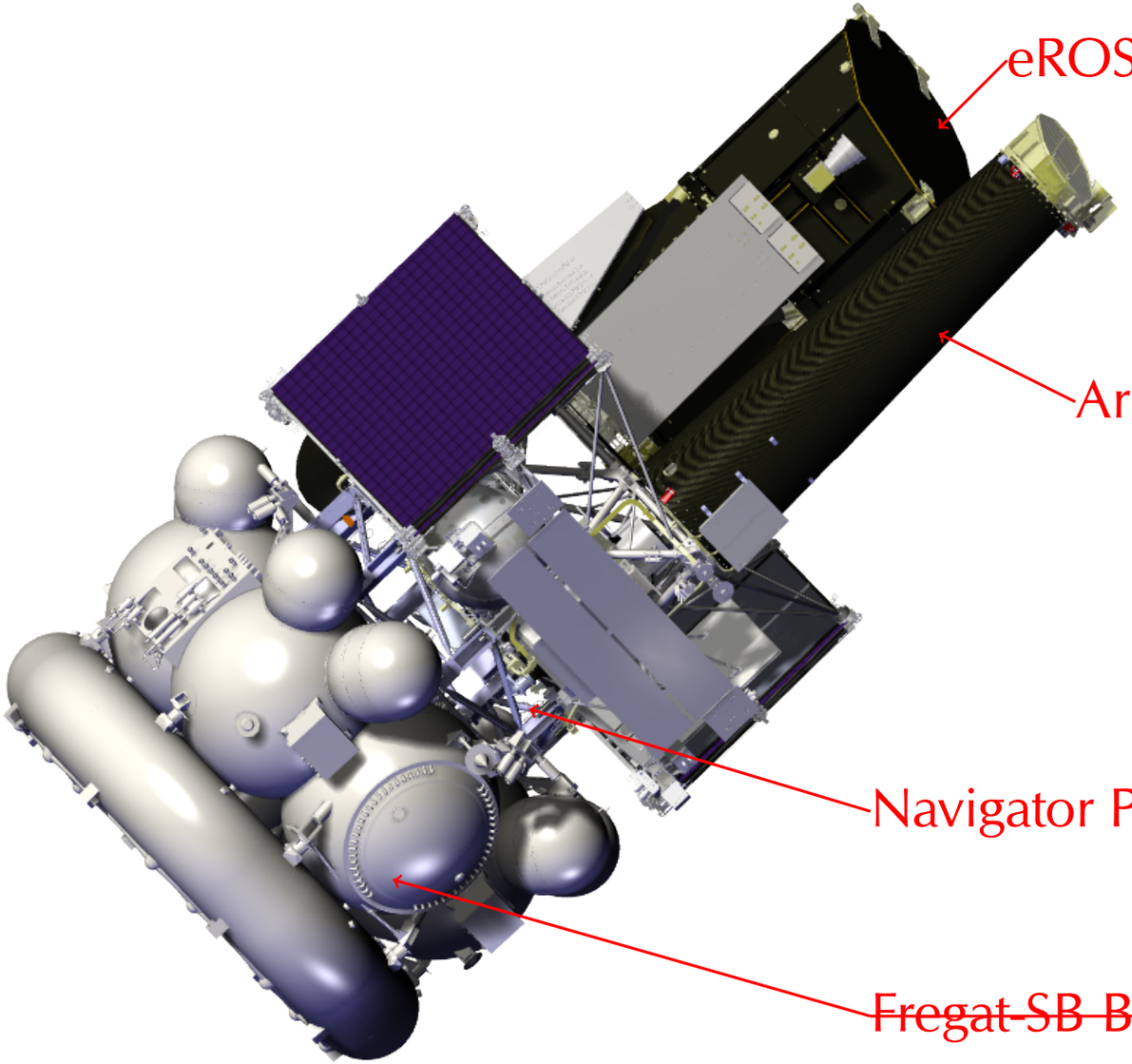
Industry:

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

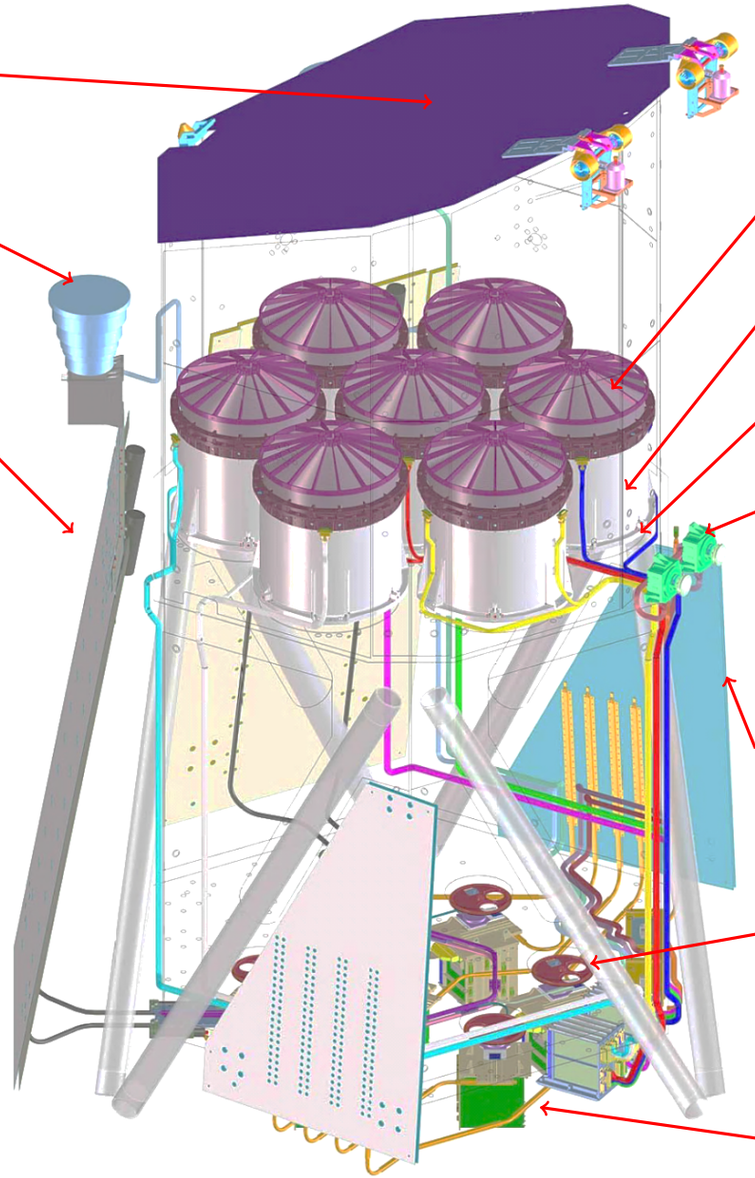
+ many small companies

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

Spectrum-X-Gamma



eROSITA



star sensors (2)

Radiatoren (2)

X-ray baffles (7)

mirror (7)

electron diverters (7)

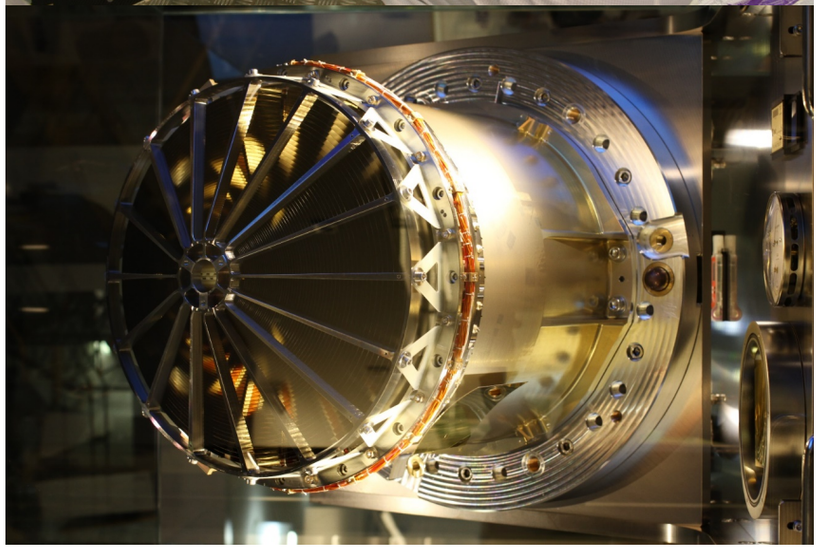
sun sensor (2)

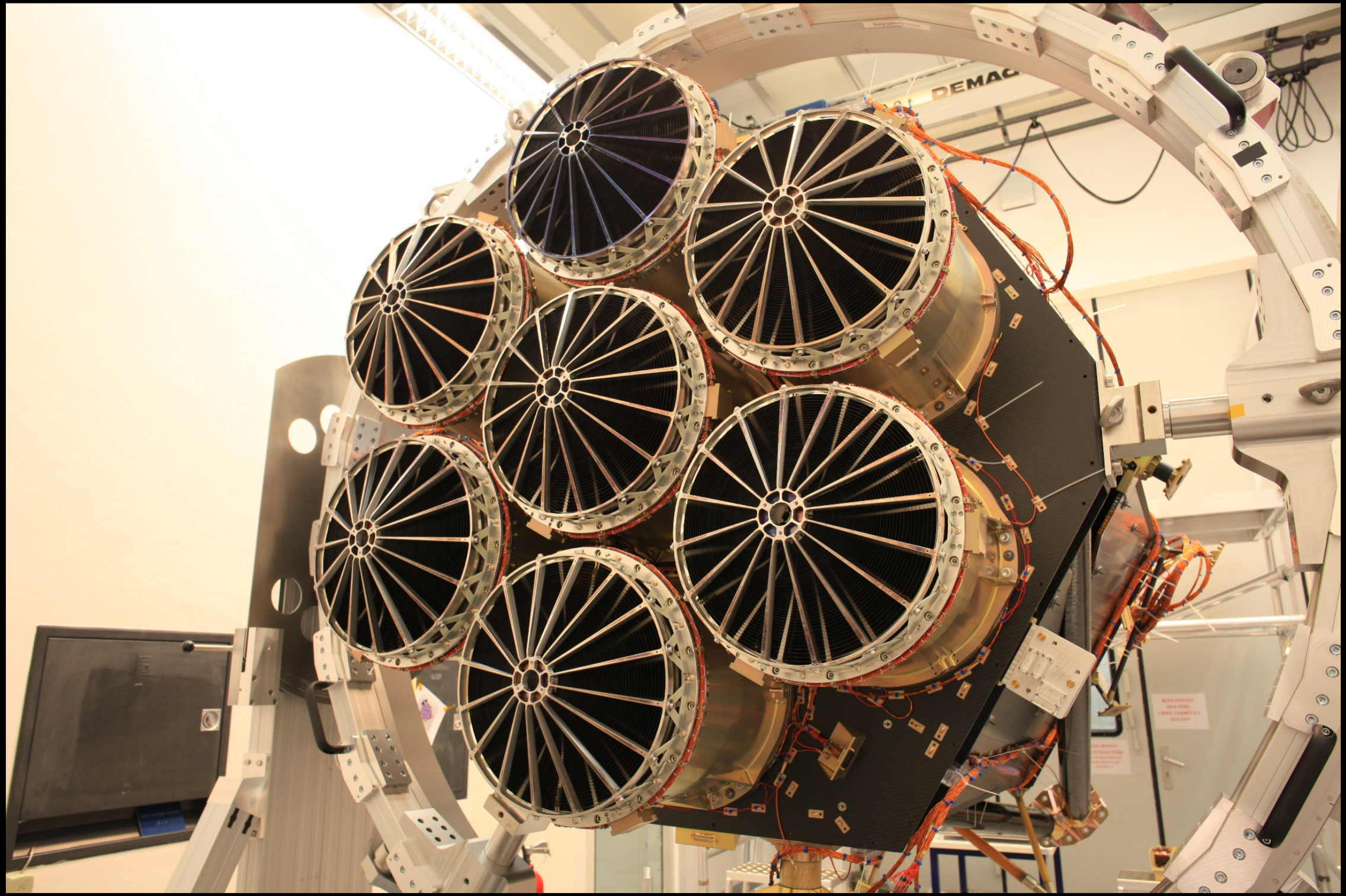
radiators (2)

cameras, electronics

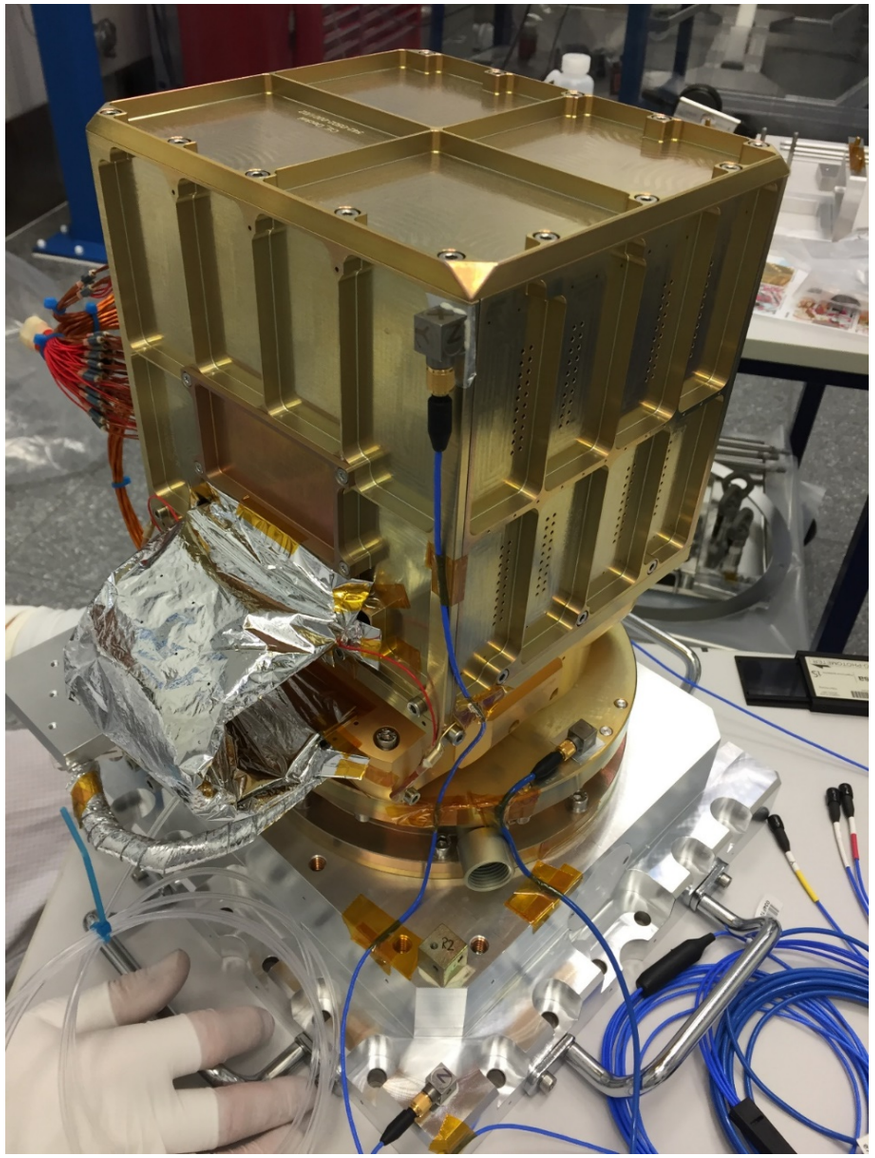
cooling system

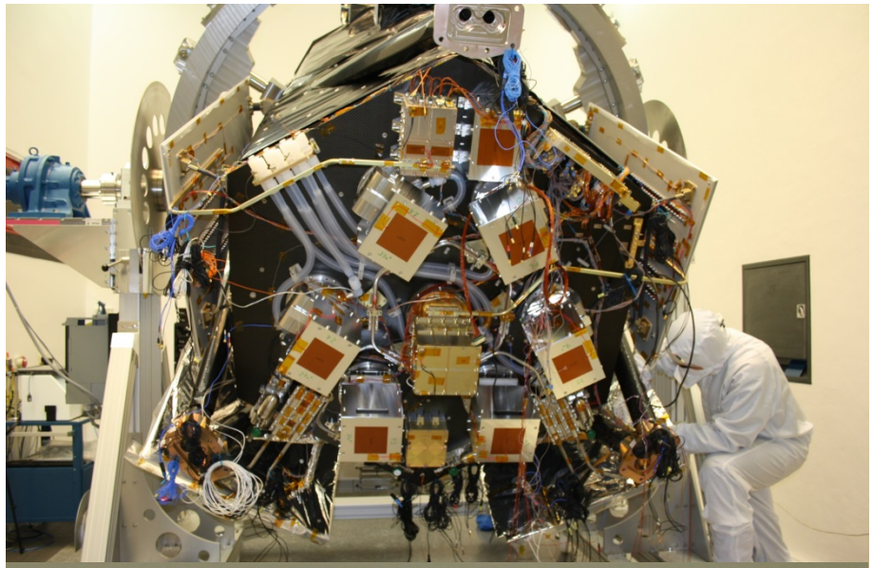
Mirrors

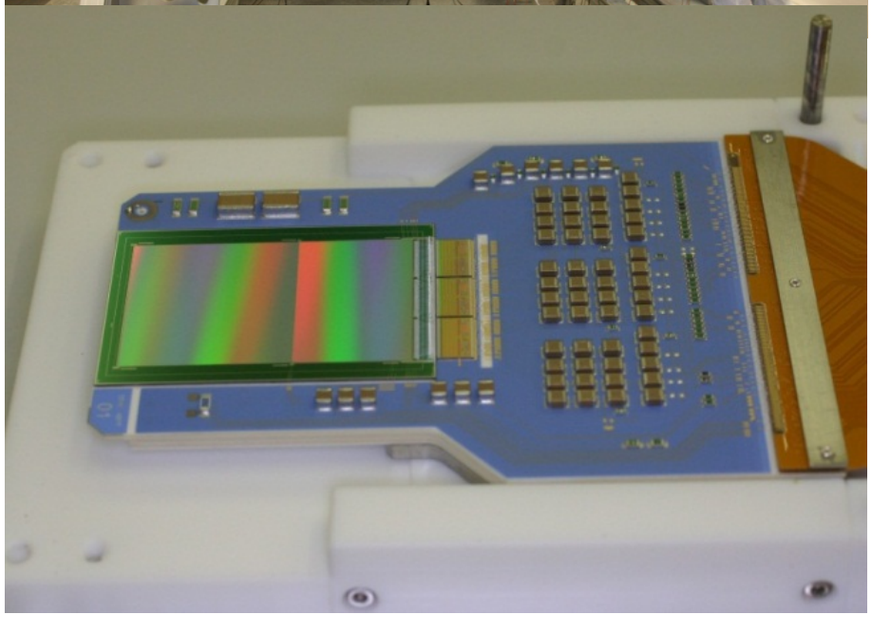


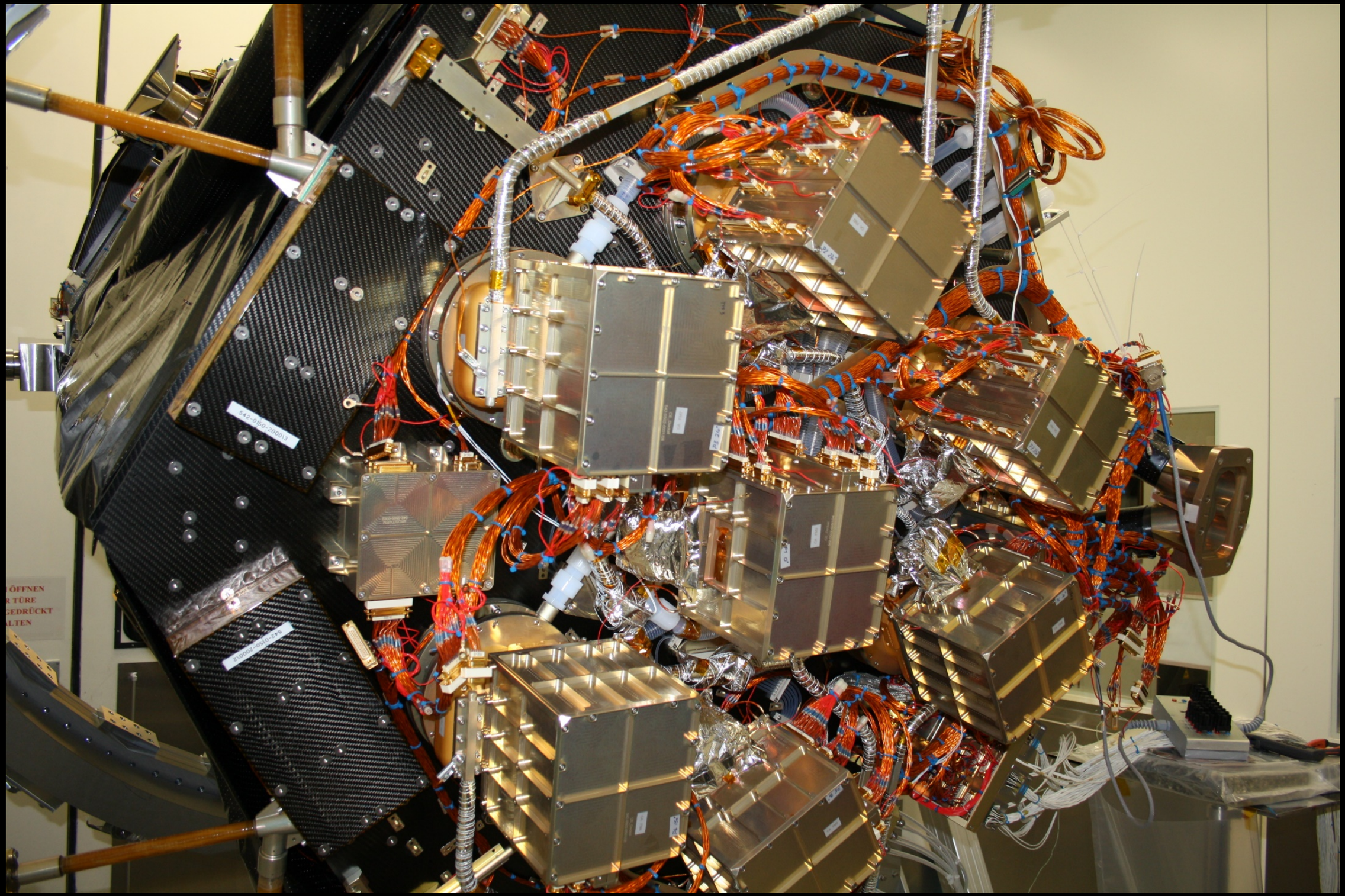


Cameras










VQ-BHE
AC 56
M
Flughafen
München
AC 56

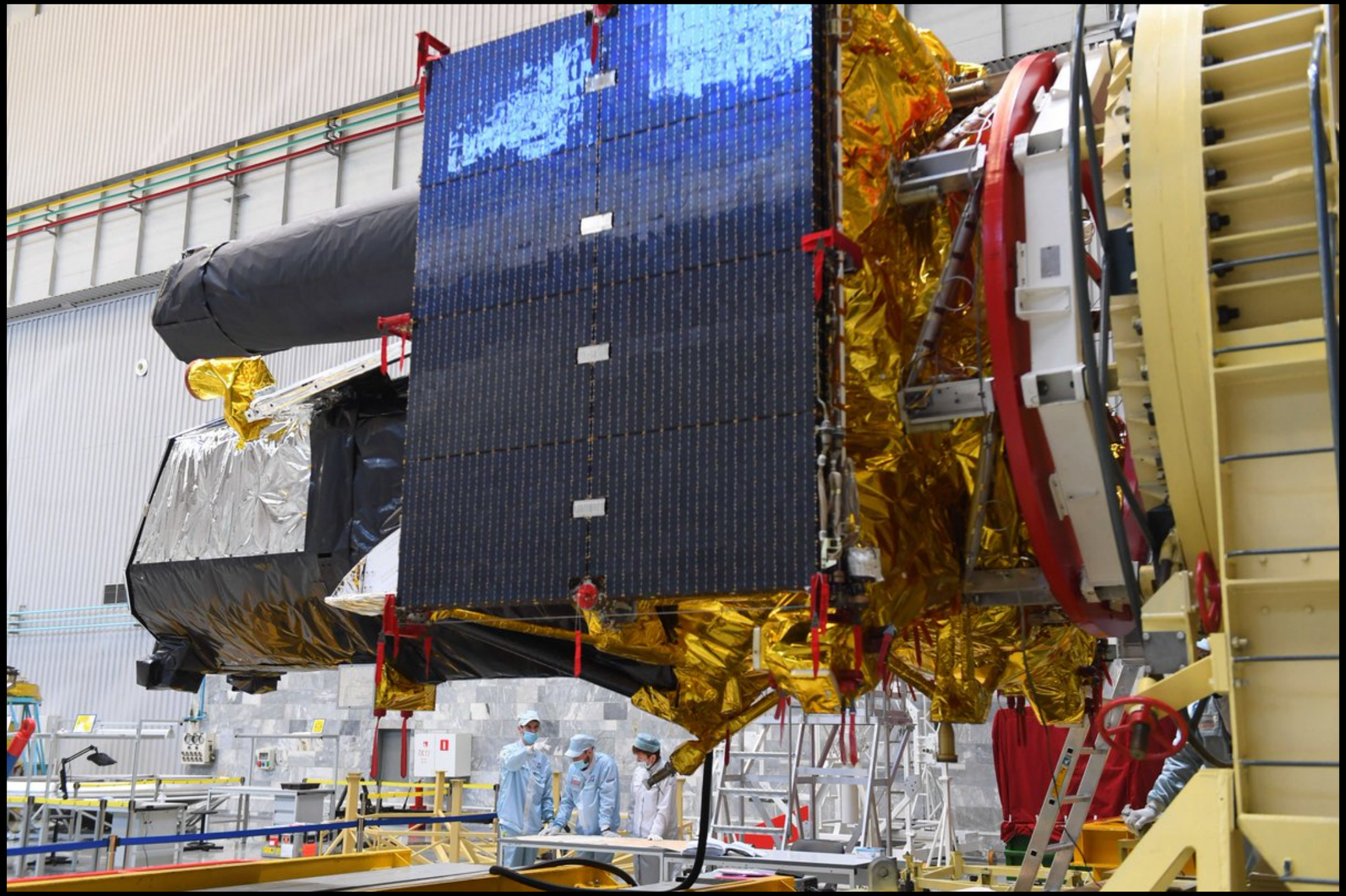

AirBridge
TREPEL
AL 350


HBSU 204955 0
22G1
MAX. GR. 30.480 KG 67.200 LB
TARE 2.150 KG 4.740 LB
NET 28.330 KG 62.460 LB
CU. CAP. 33.1 CUM 1.170 CUFT
13R
9R
14R
10R
8R 9R
STA 1300
9R 10R
STA 1200
8L
9L 8L

P. Predehl (MPE)

P. Predehl (MPE)


ТБО
900
ТБО
900



IKS

ILS


КОСМИЧЕСКАЯ АСТРОФИЗИЧЕСКАЯ ОБСЕРВАТОРИЯ
ASTROPHYSICAL SPACE OBSERVATORY
«СПЕКТР-РГ»
SPEKTR-RG
ИКИ

ILS

ILS

ILS

J. Wilms

J. Wilms

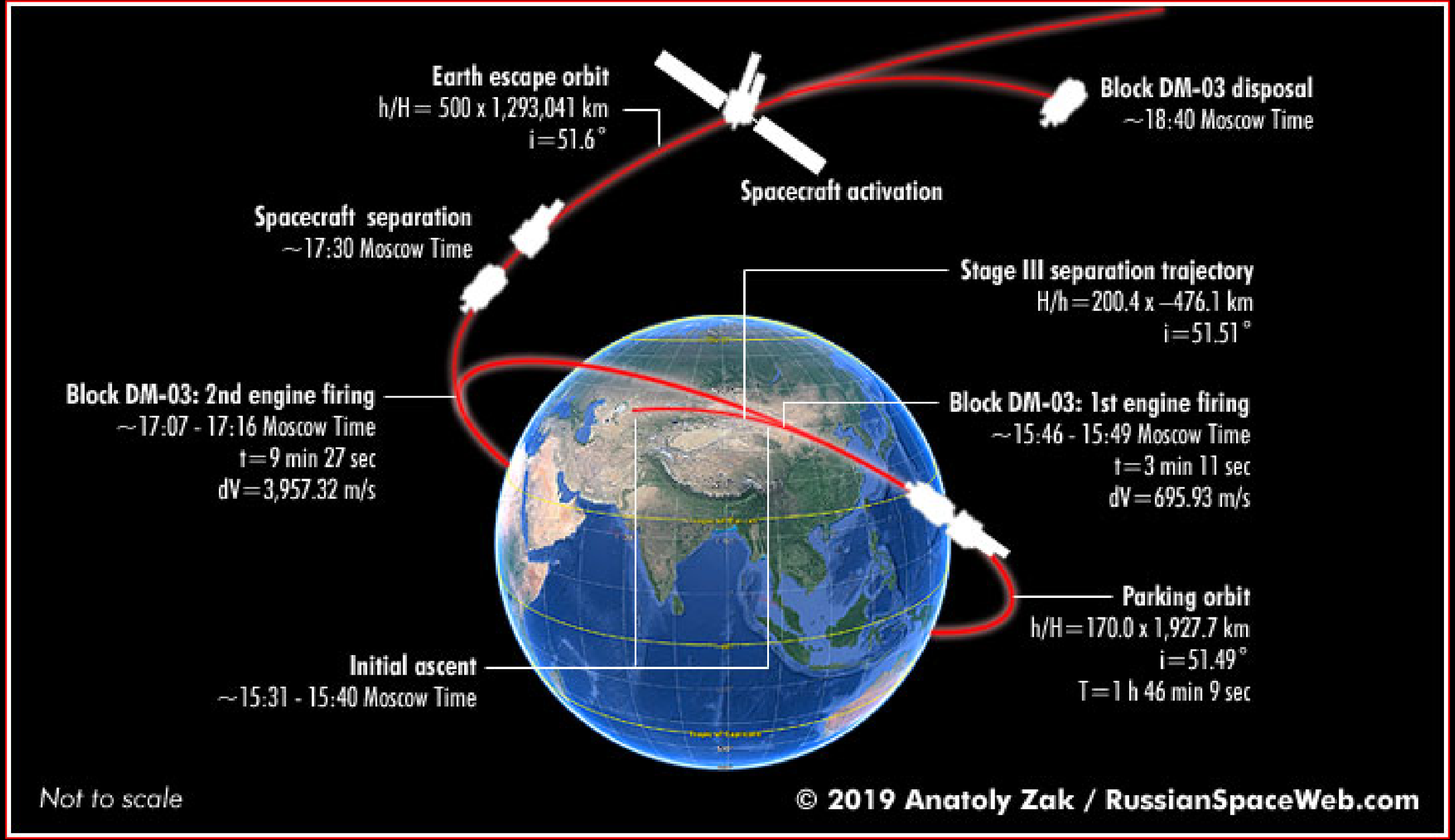
J. Wilms

C. Grossberger

Roscosmos

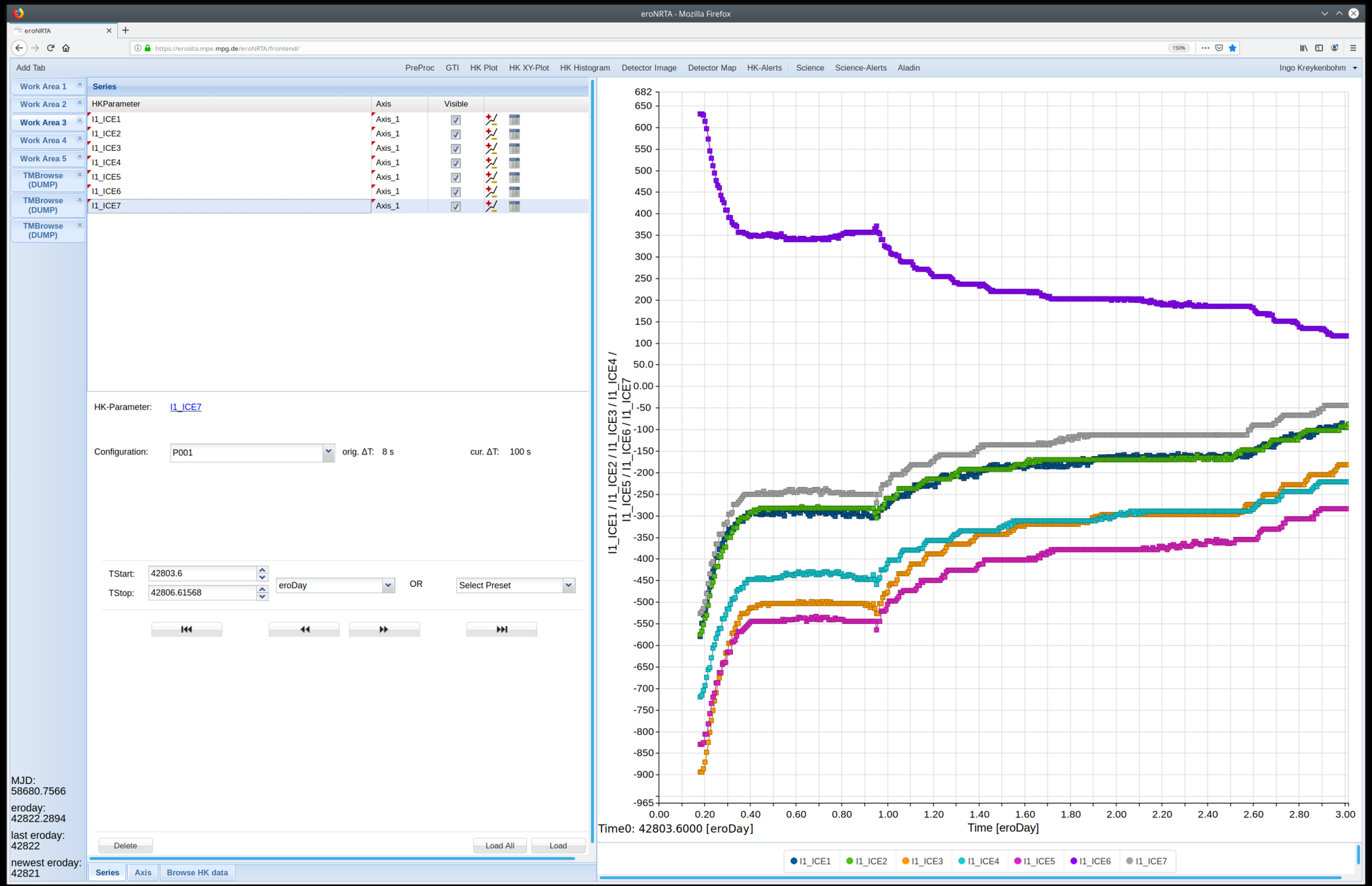
Roscosmos

V. Burwitz



Russian Space Web

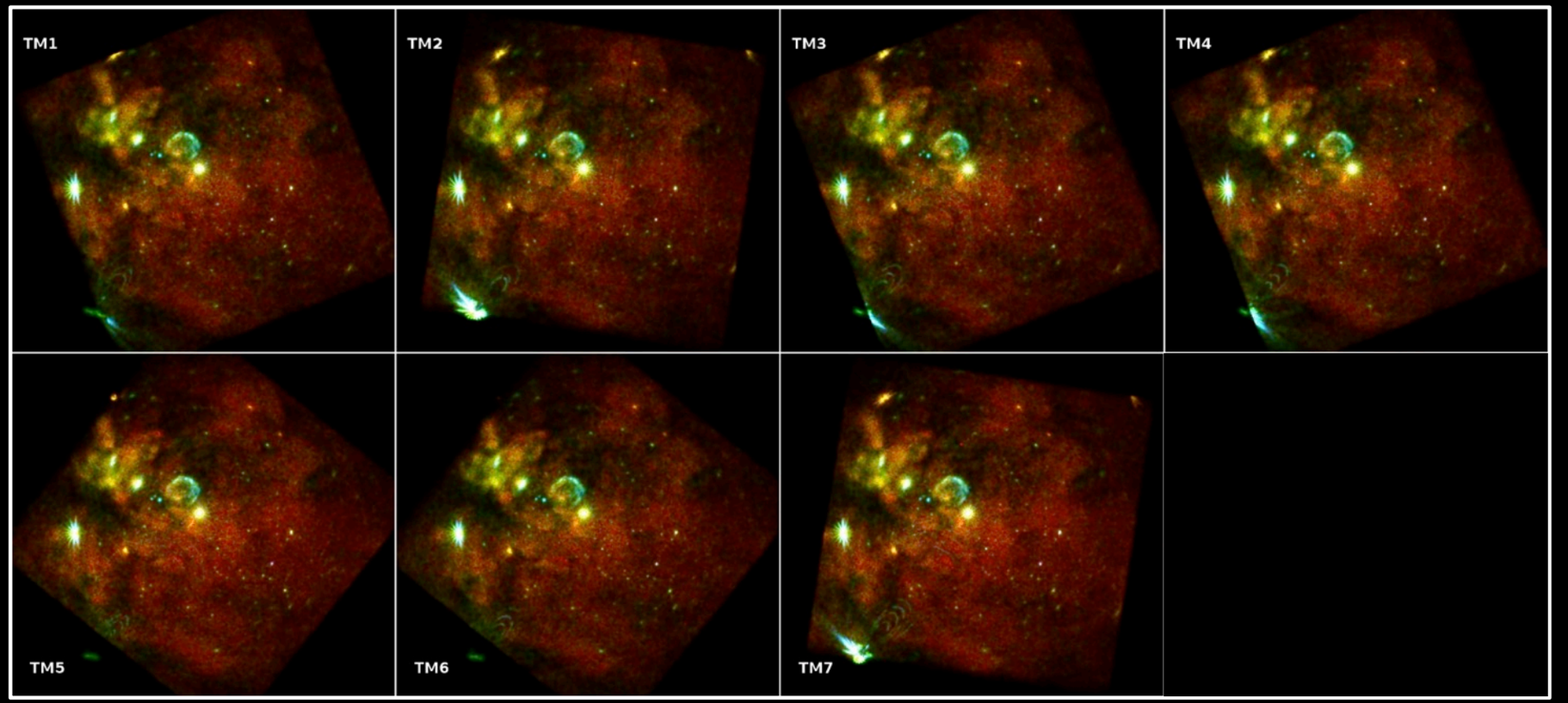
T. Dauser



I. Kreykenbohm

First light: Large Magellanic Cloud

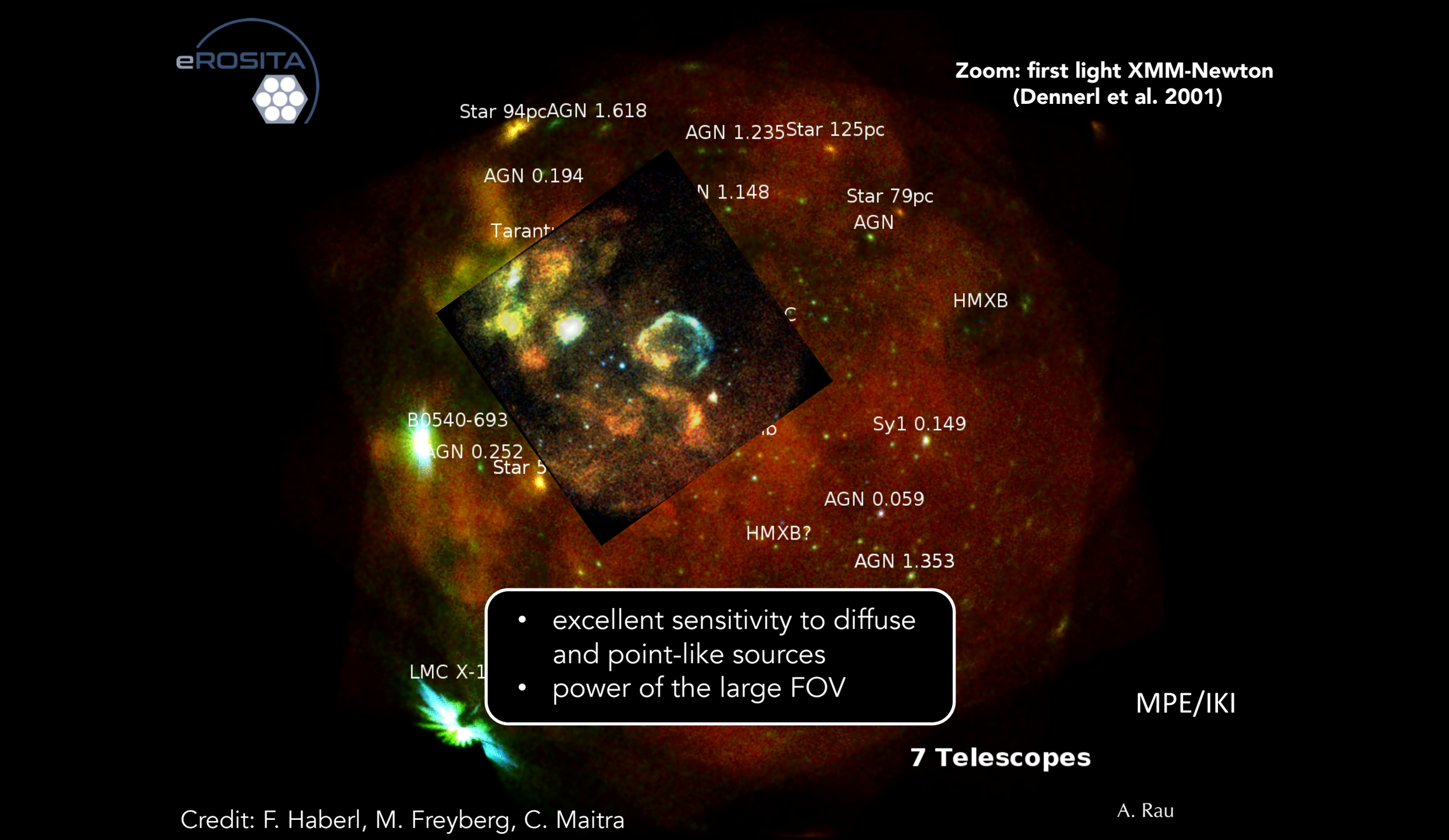
SRG/eROSITA (0.2-4.5 keV)



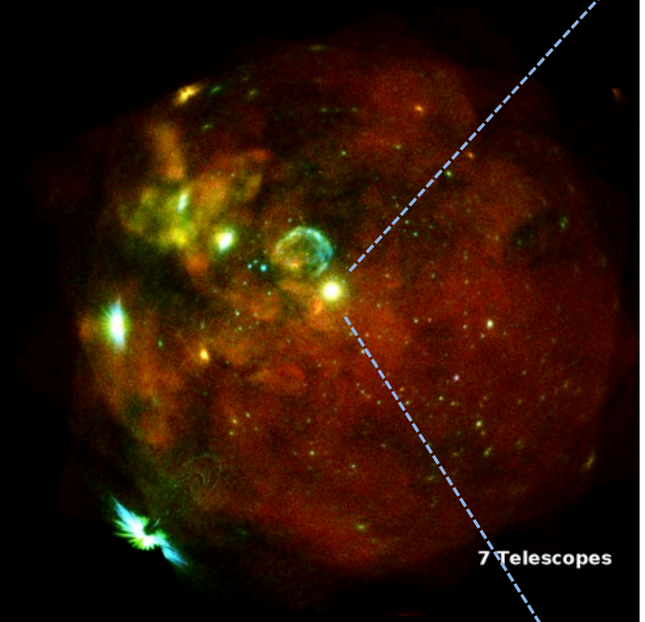
LMC/SN1987A

MPE/IKI

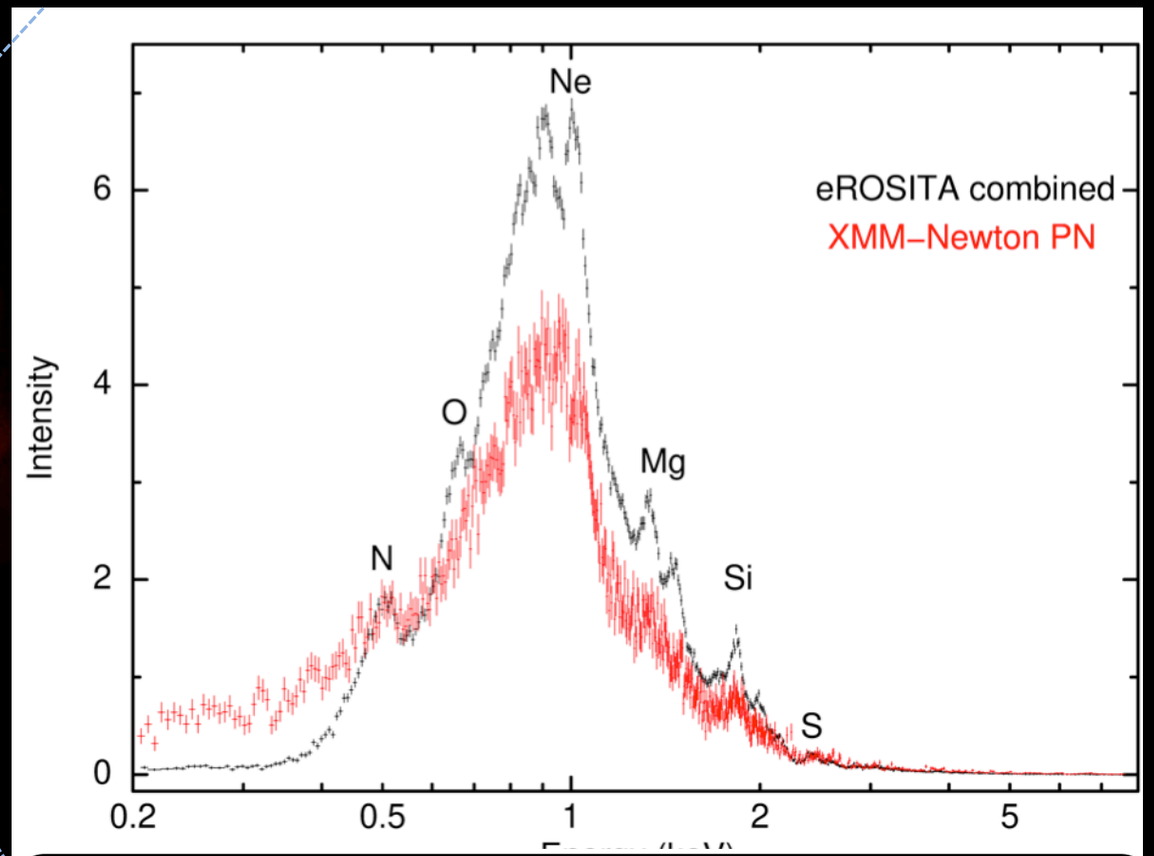
Credit: F. Haberl, M. Freyberg, C. Maitra


Zoom: first light XMM-Newton
(Dennerl et al. 2001)
Star 94pc
AGN 1.618
AGN 1.235
Star 125pc
AGN 0.194
Star 79pc
AGN
HMXB
B0540-693
Sy1 0.149
AGN 0.059
HMXB?
AGN 1.353
• excellent sensitivity to diffuse and point-like sources
• power of the large FOV
MPE/IKI
7 Telescopes
Credit: F. Haberl, M. Freyberg, C. Maitra
A. Rau

SRG/eROSITA



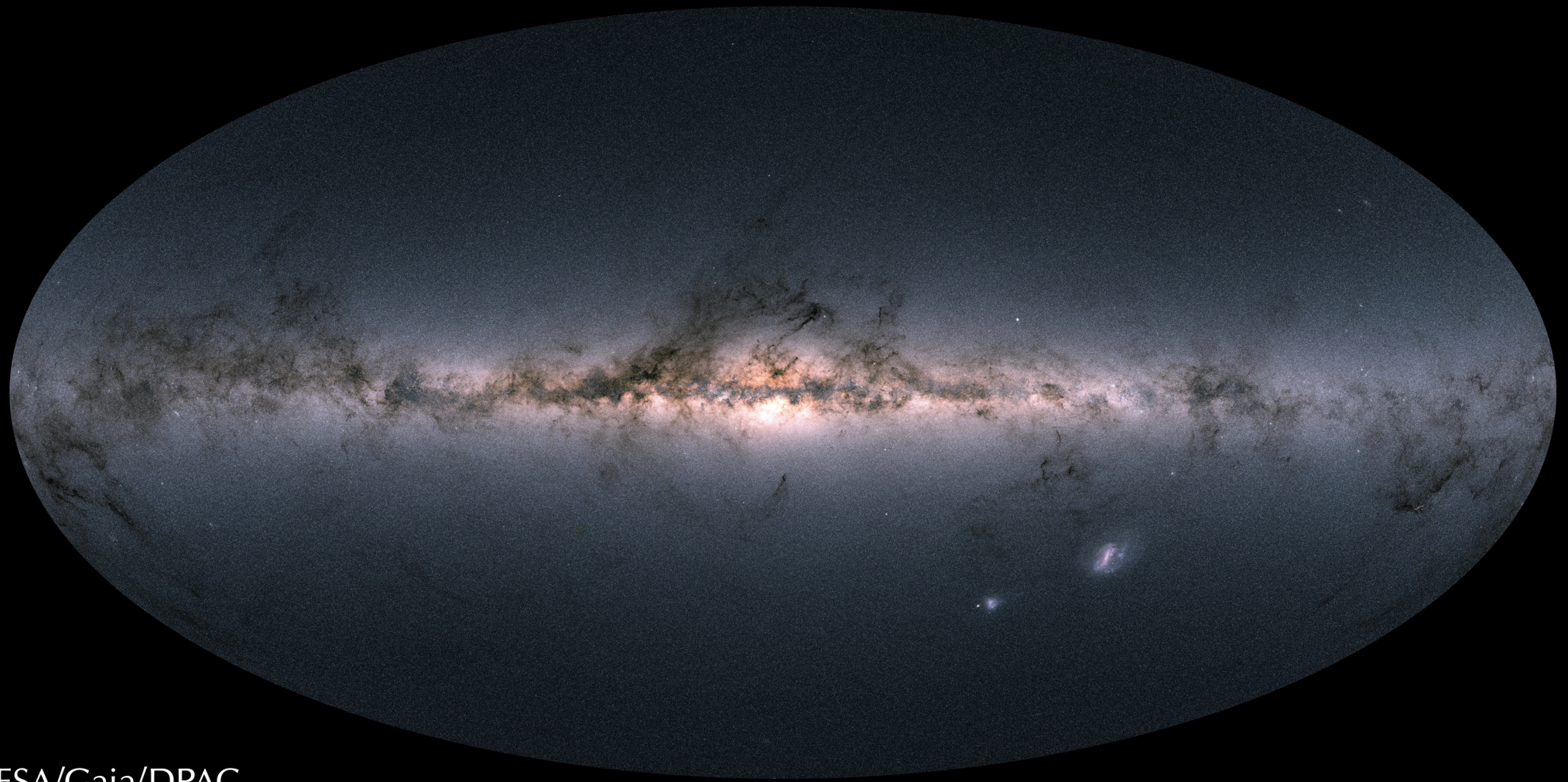
SN 1987A in the LMC



- higher throughput than XMM-Newton PN
- spectral resolution: best CCD-camera in space
  50 eV@0.3 keV, 77 eV@1.5 keV

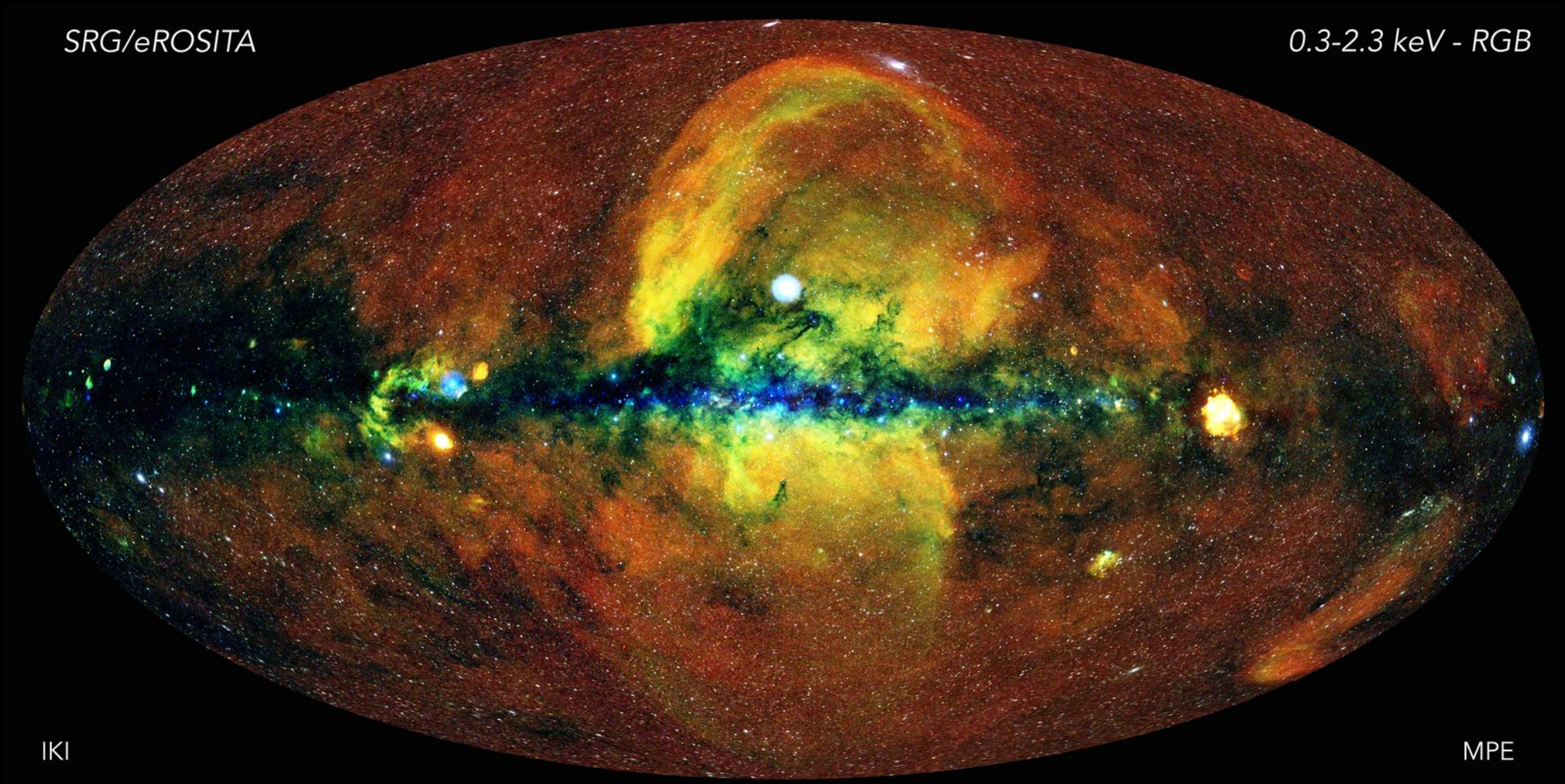
Haberl, Maitra, Freyberg. MPE,

The visual Sky

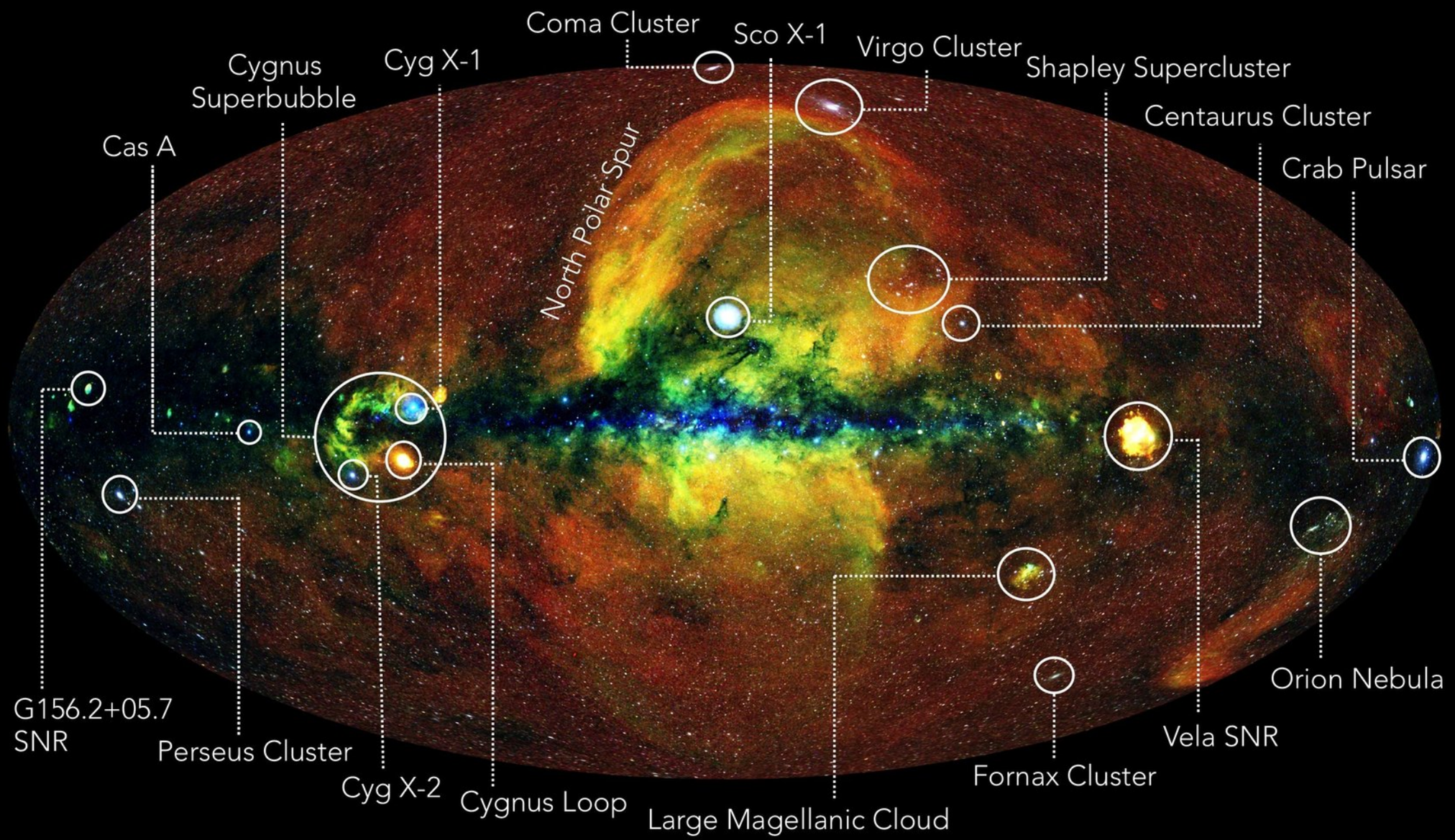


ESA/Gaia/DPAC

The first eROSITA All Sky Survey

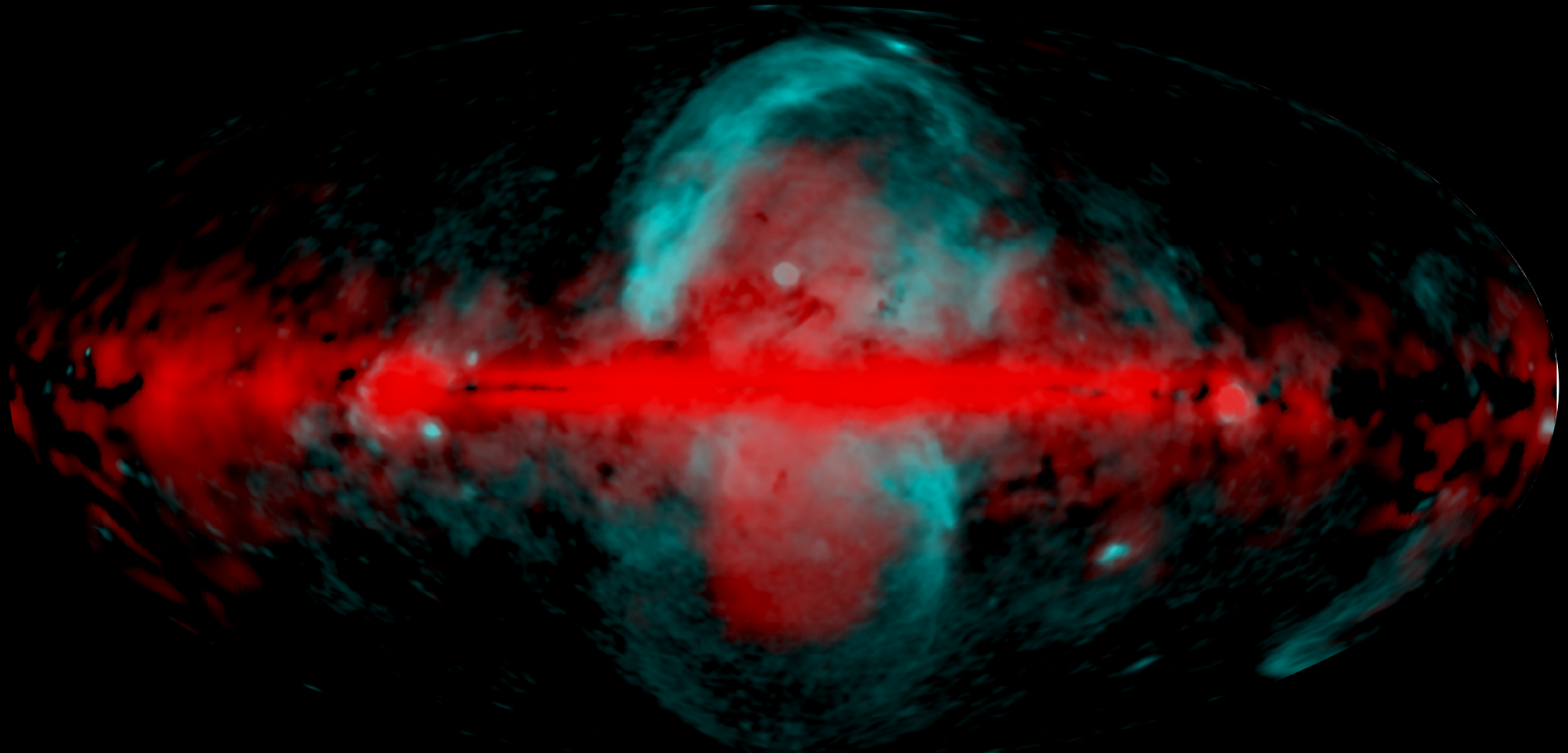


Navigating the eROSITA X-ray sky



- 1.1 M sources
- >5k galaxy clusters

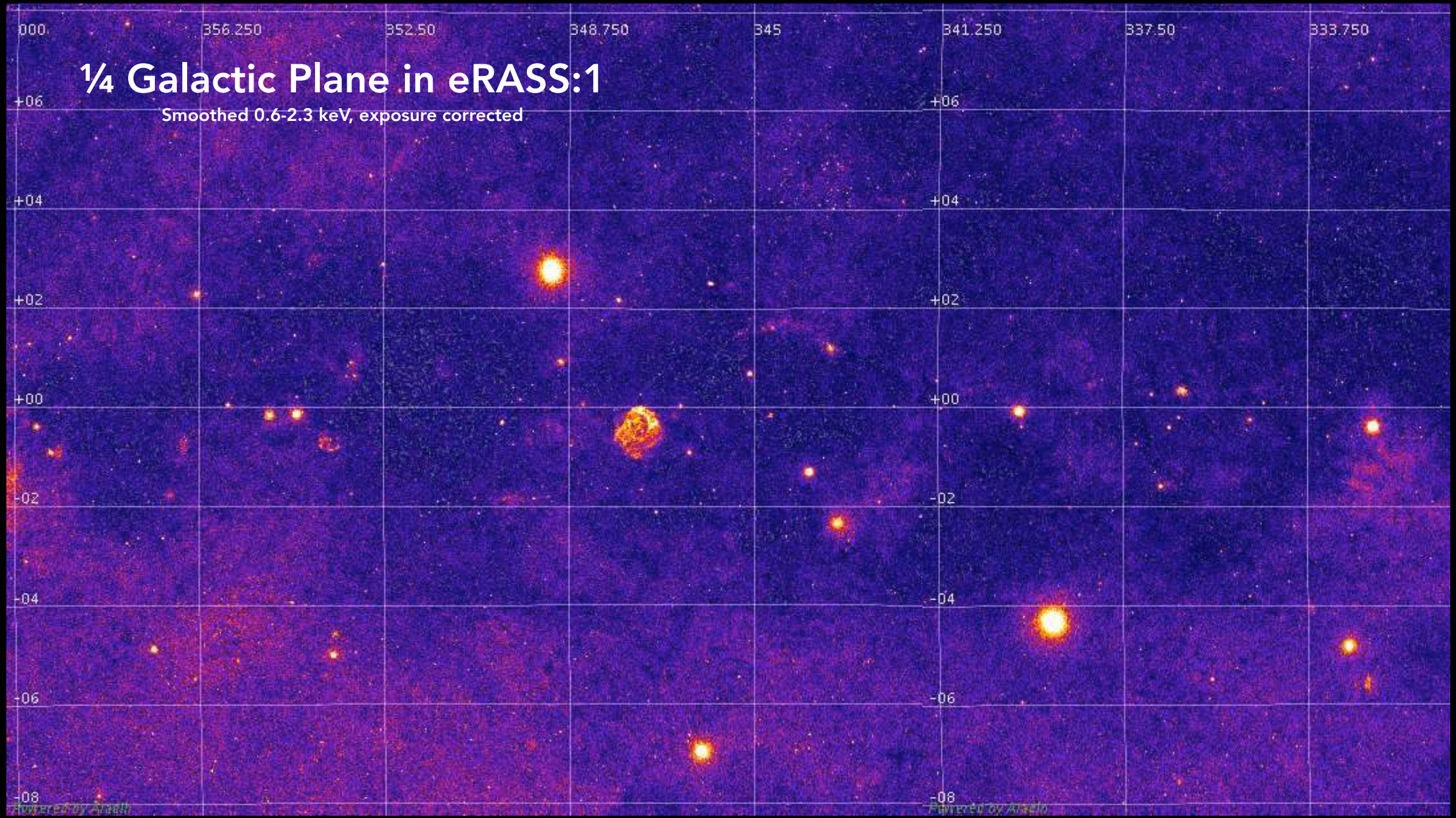
eROSITA and the Fermi bubbles



Predehl et al., 2020, Nature 588, 227 blue: X-rays (0.3–2.3 keV), red: γ-rays (20 MeV–300 GeV)

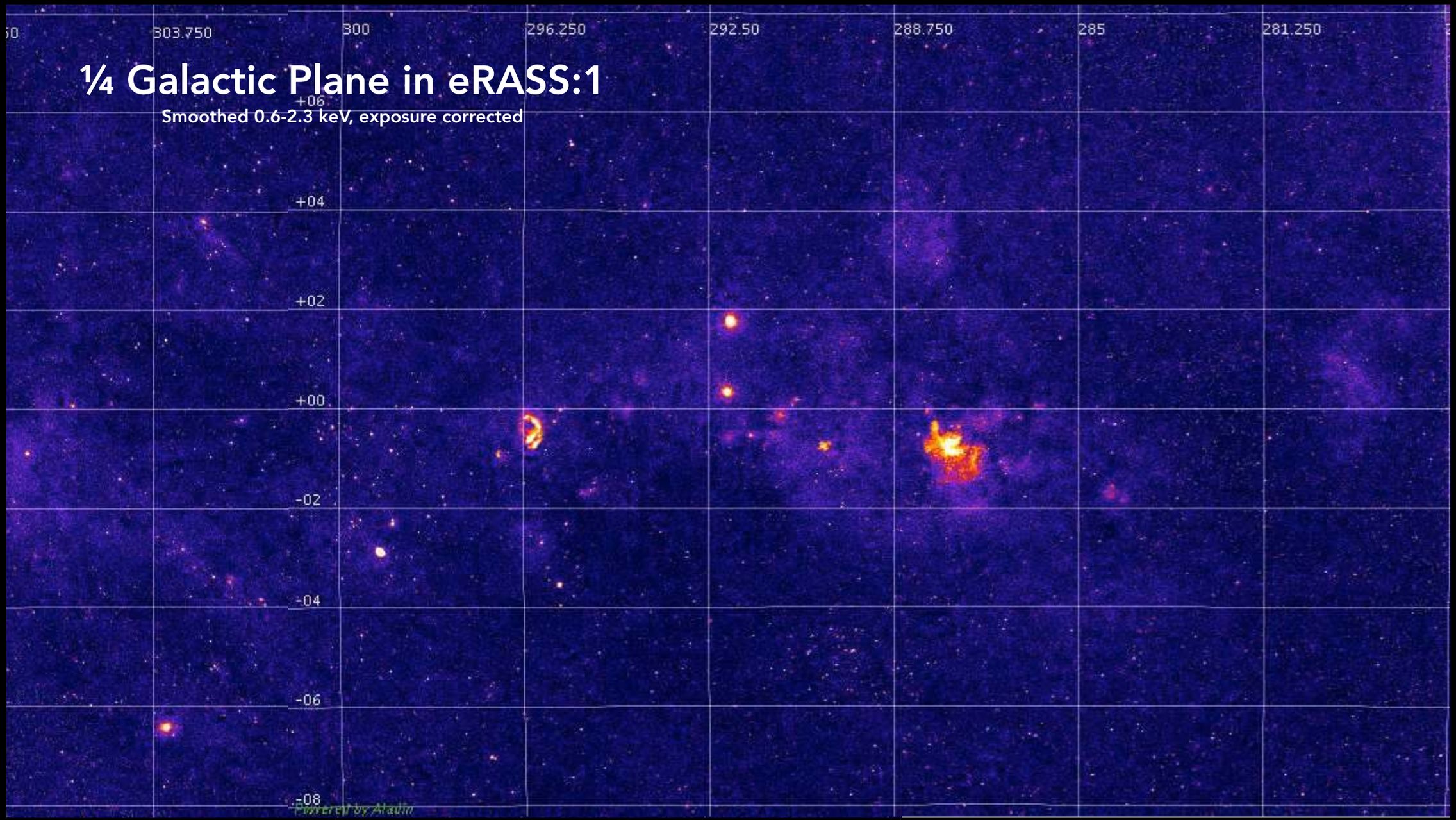
$L_X \sim 1 \times 10^{39}\,\mathrm{erg\,s^{-1}} \sim 25 \times 10^6\,L_\odot$

need $10^{41}\,\mathrm{erg\,s^{-1}}$ for a few Myr (Star Burst or Activity in Sgr A*)



¼ Galactic Plane in eRASS:1

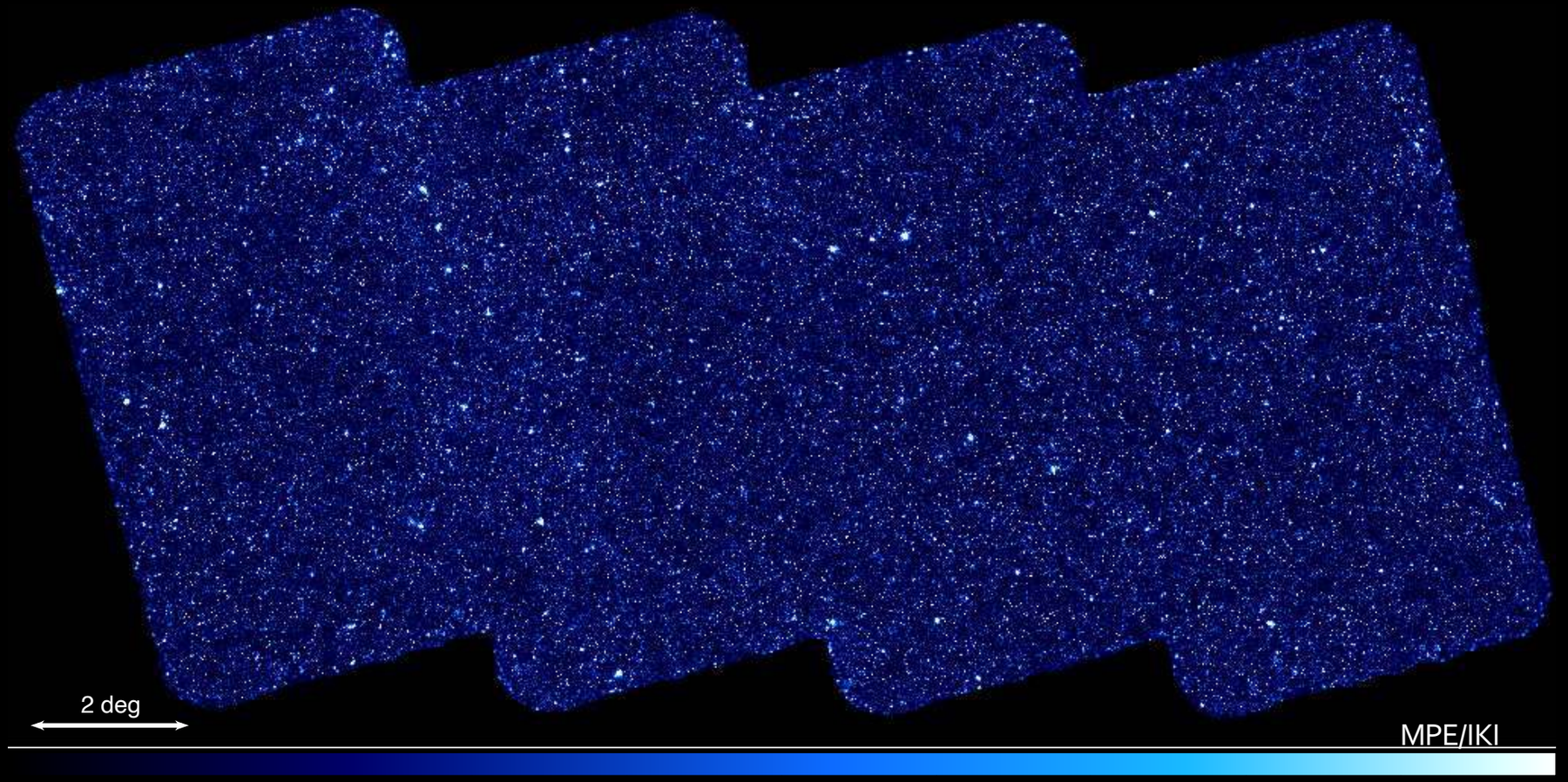
Smoothed 0.6-2.3 keV, exposure corrected



¼ Galactic Plane in eRASS:1

Smoothed 0.6-2.3 keV, exposure corrected

eROSITA Final Equatorial-Depth Survey

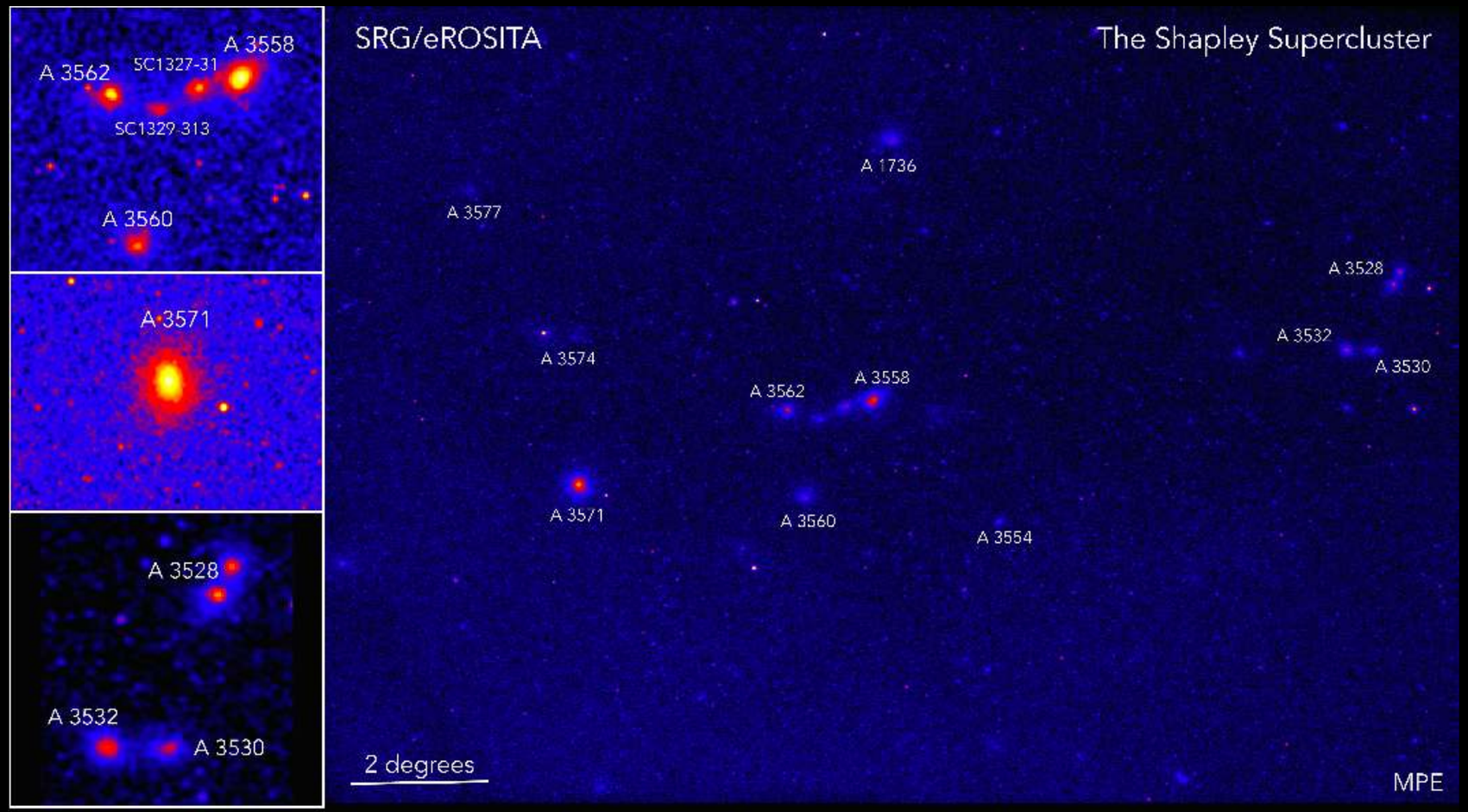


Credit: H. Brunner, M. Ramos-Ceja

Exposure corrected image in the 0.5–2.0 keV band

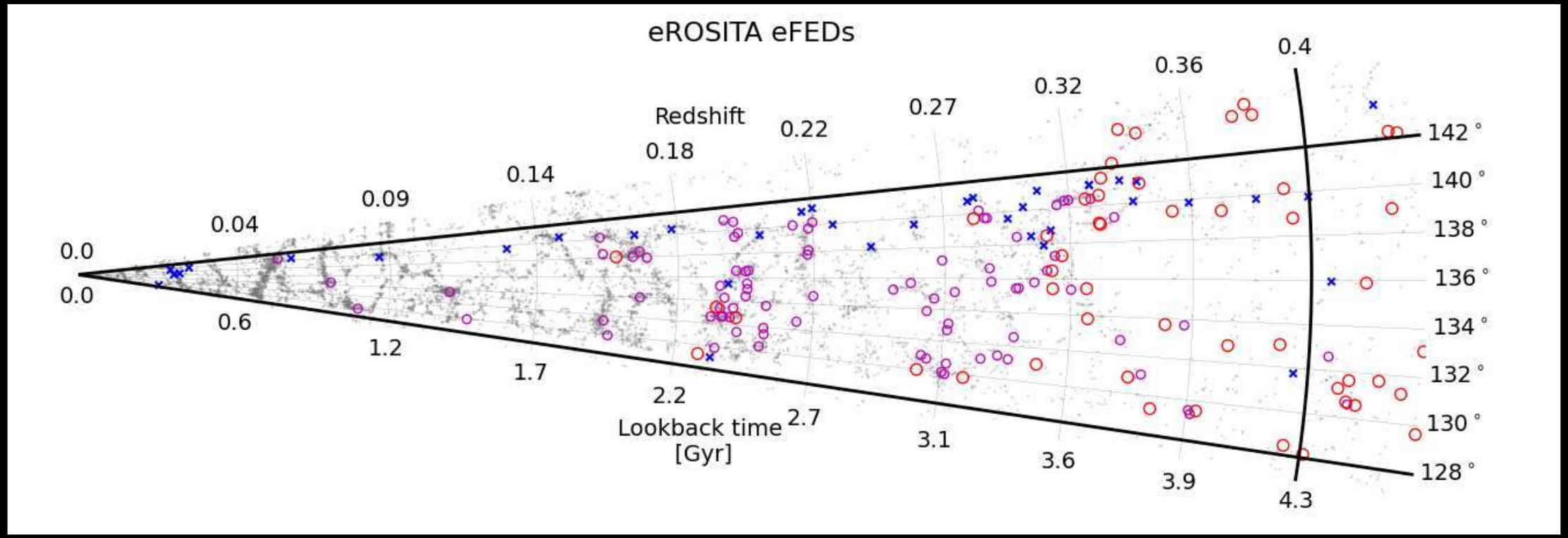
E. Bulbul

Mapping the Large Scale Structure



Credit: E. Bulbul, J. Sanders

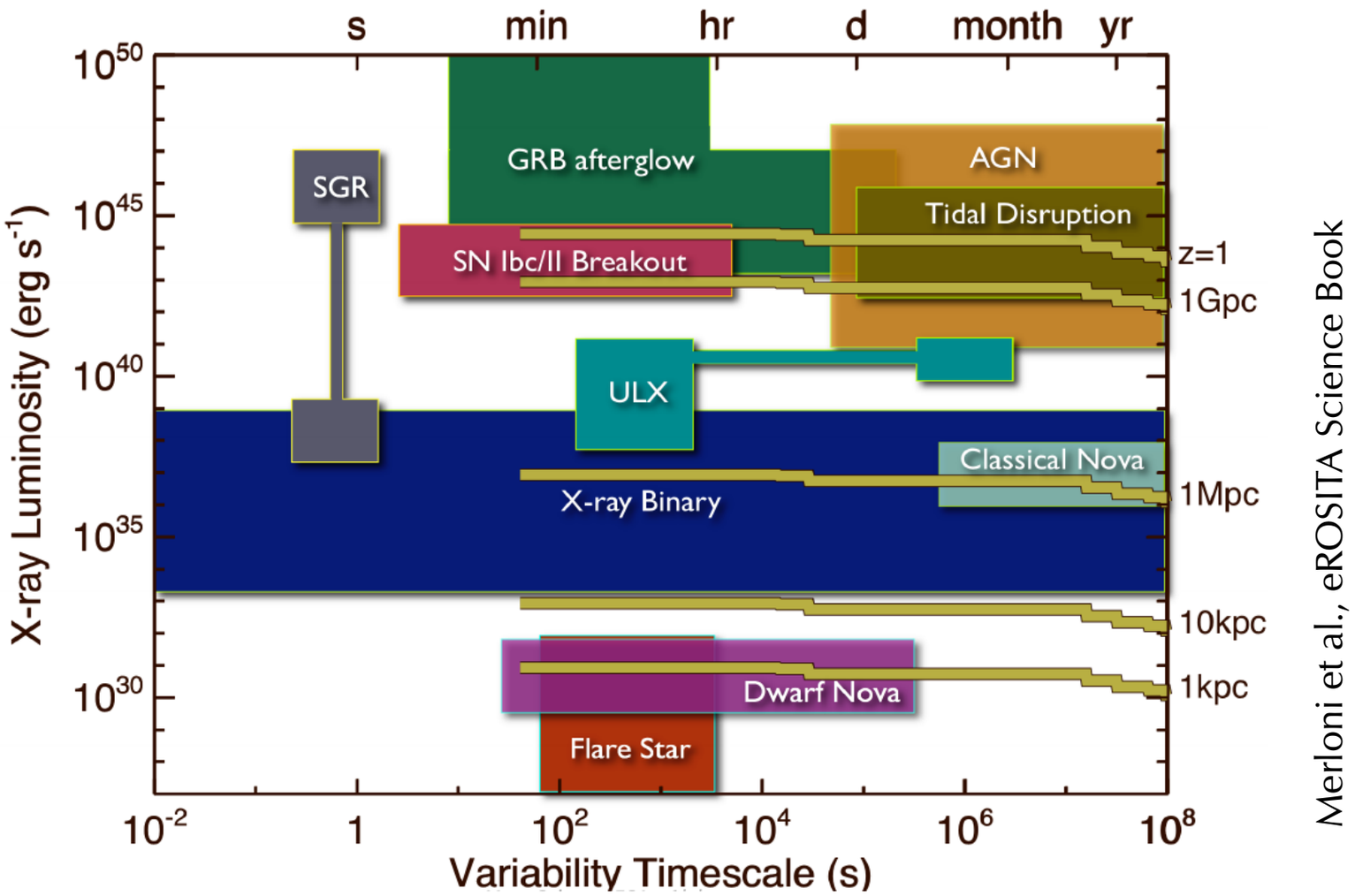
Large Scale Structure in eFEDS



Credit: J. Comparat

E. Bulbul

Variability with eROSITA

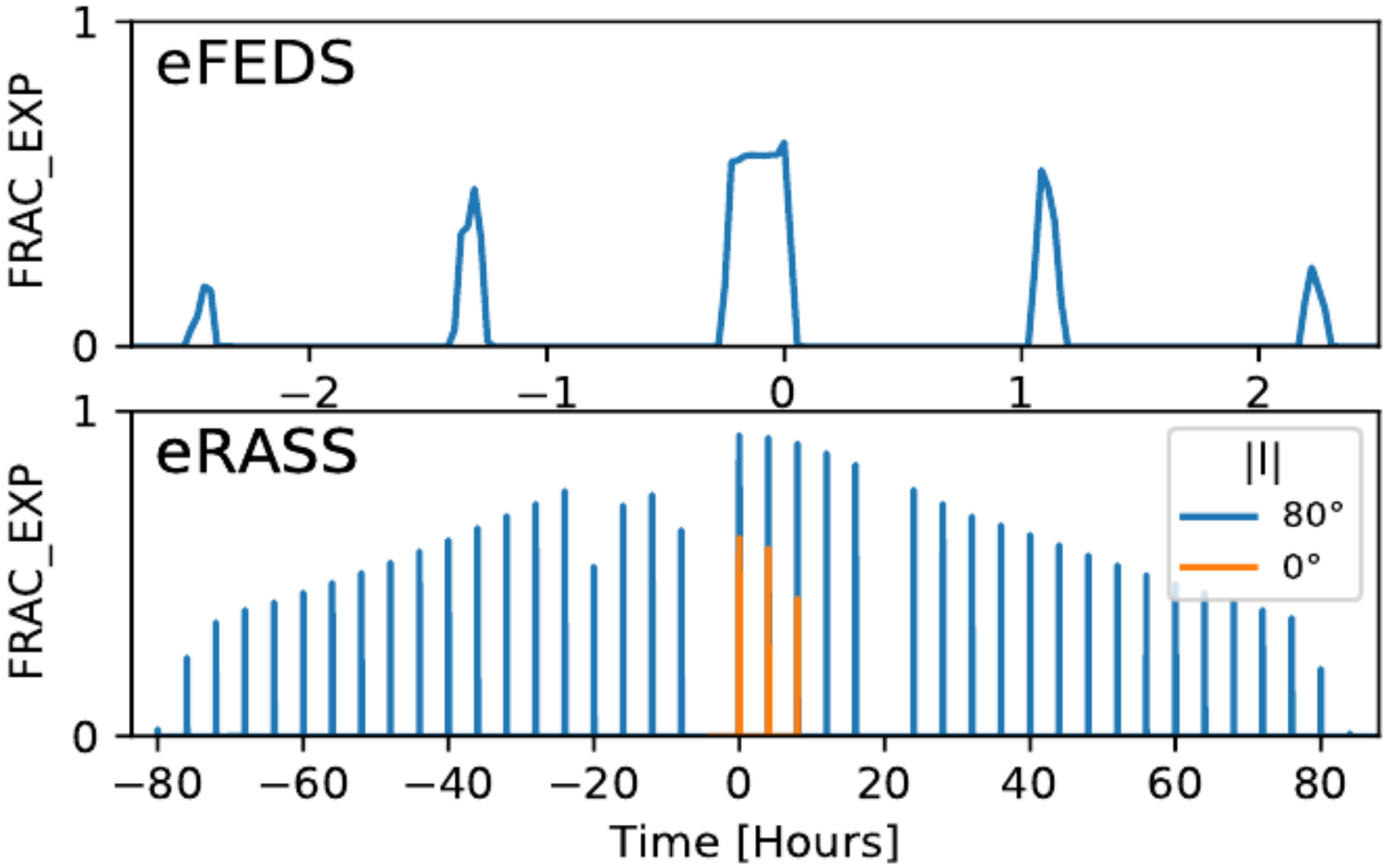


Merloni et al., eROSITA Science Book

eROSITA can contribute on timescales of ~4 h and 6 Months!

$\Longrightarrow$ follow up w/other instruments necessary

Variability with eROSITA

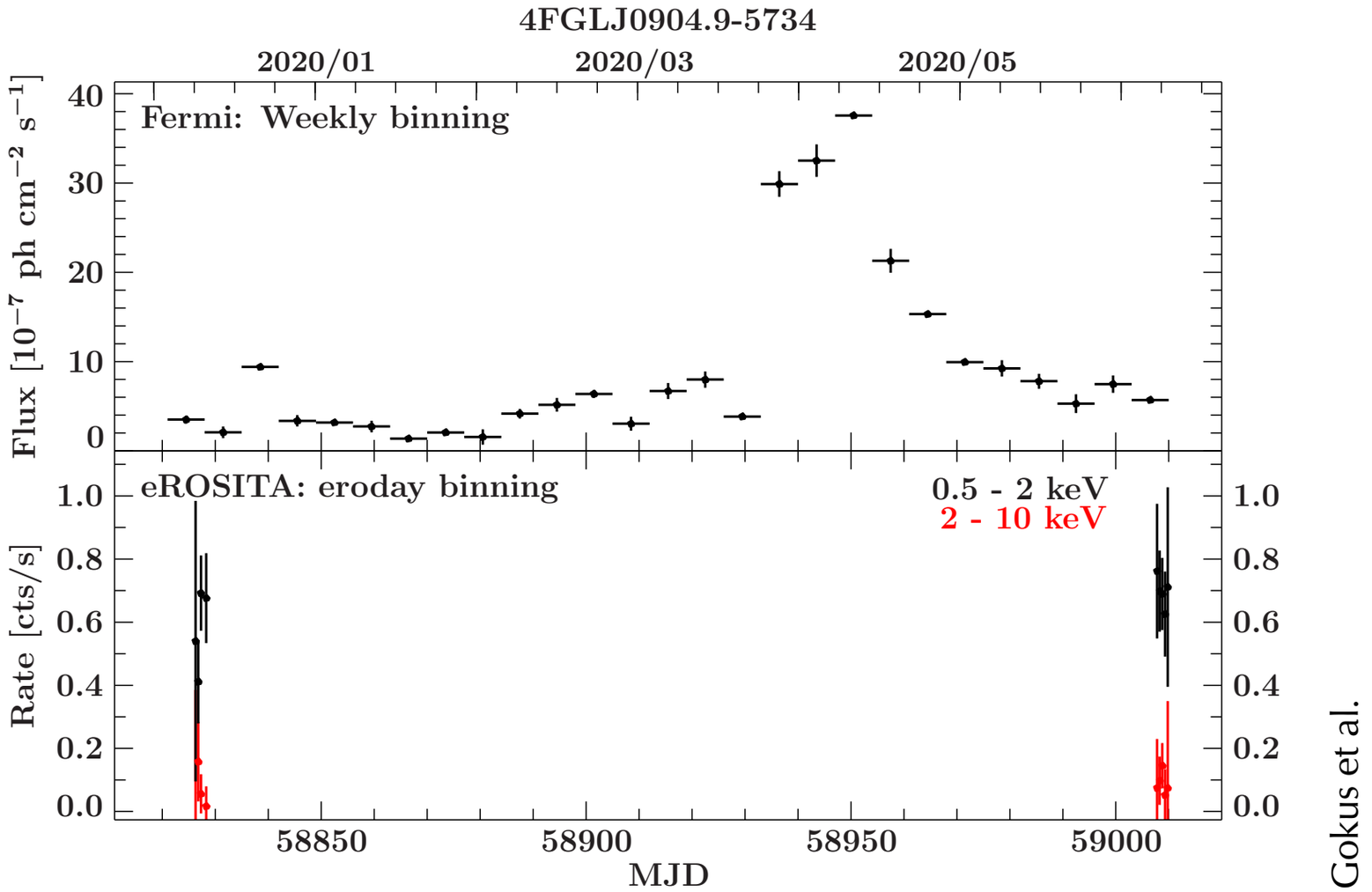


Buchner et al. (submitted)

eROSITA can contribute on timescales of ~4 h and 6 Months!

$\Longrightarrow$ follow up w/other instruments necessary

Variability with eROSITA

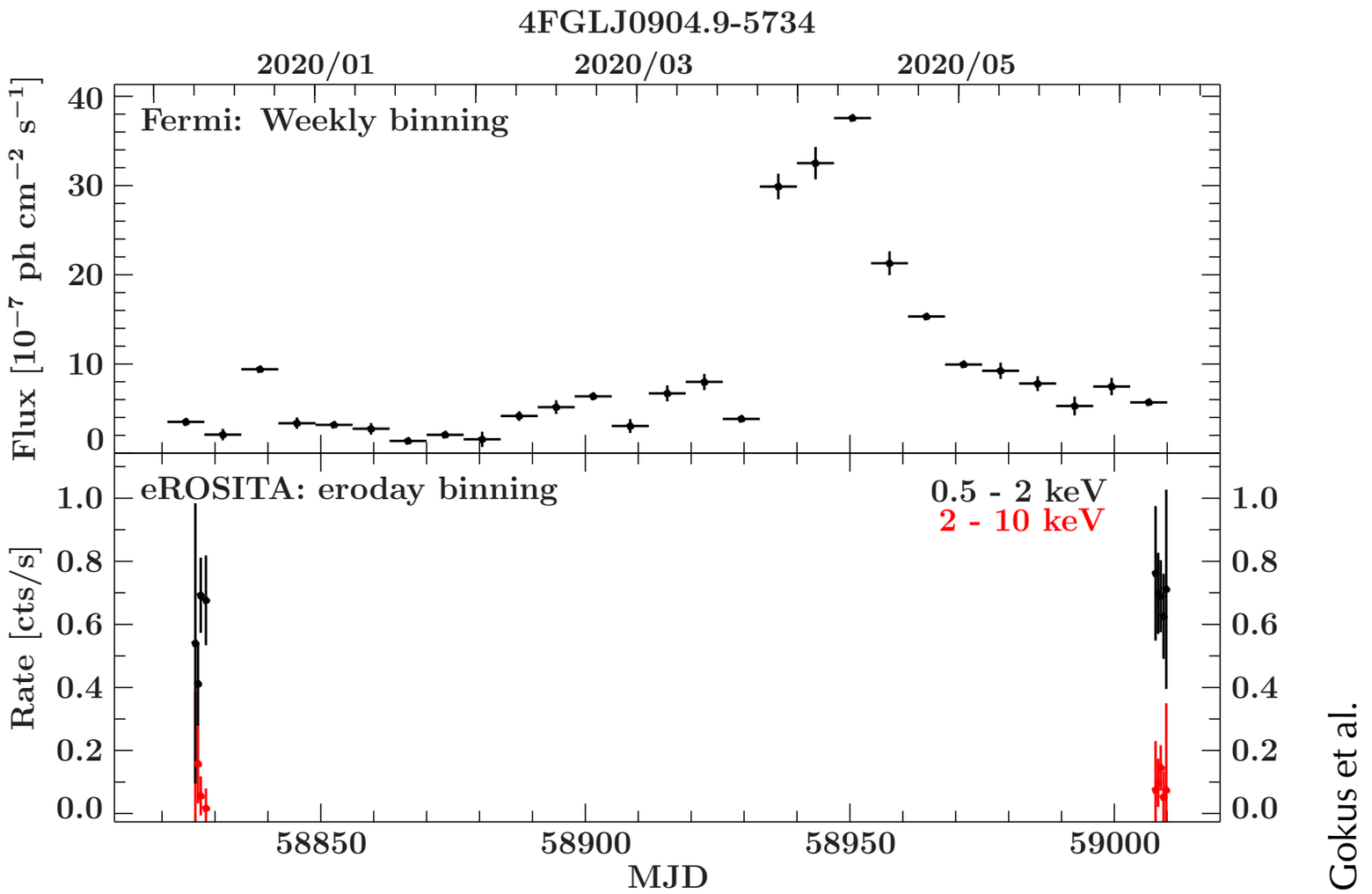


Gokus et al.

eROSITA can contribute on timescales of ~4 h and 6 Months!

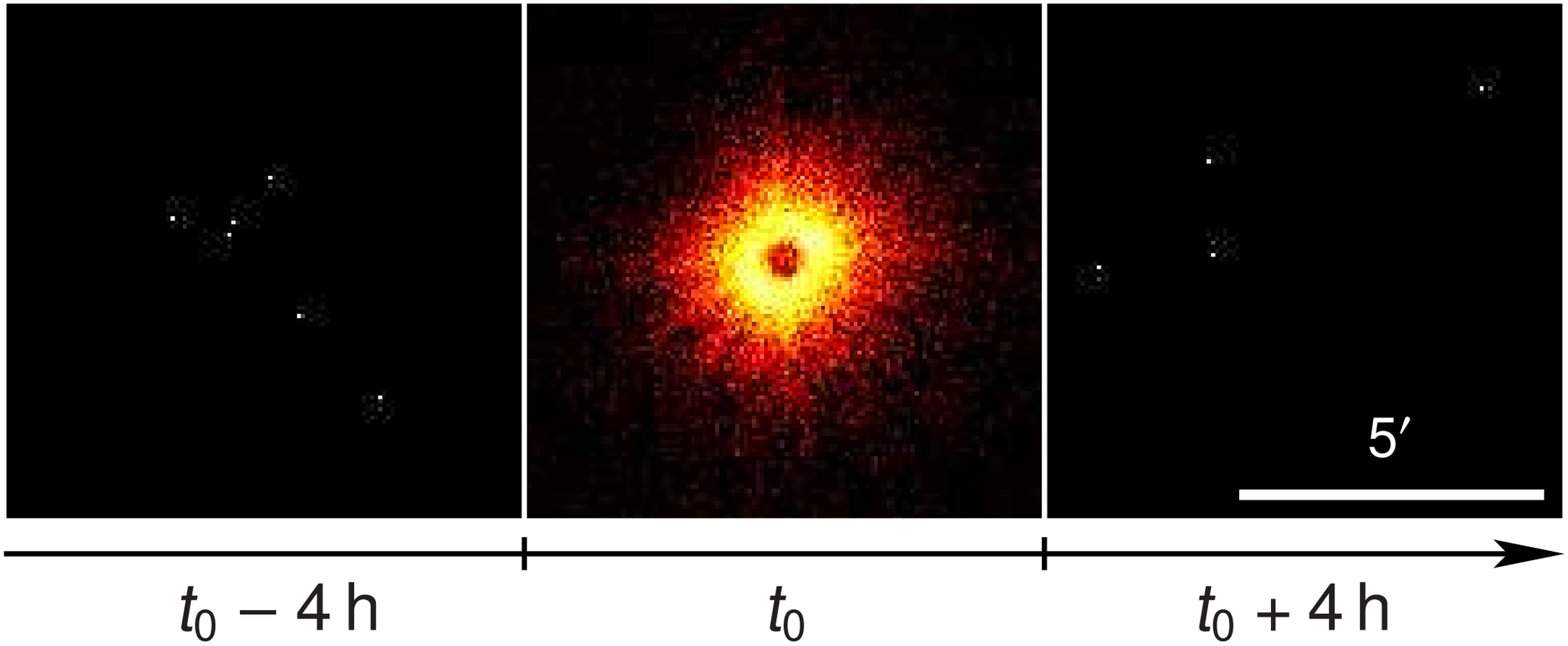
$\Longrightarrow$ follow up w/other instruments necessary

Variability with eROSITA



eROSITA excels at variability studies for large samples, and as finder for individual interesting sources.

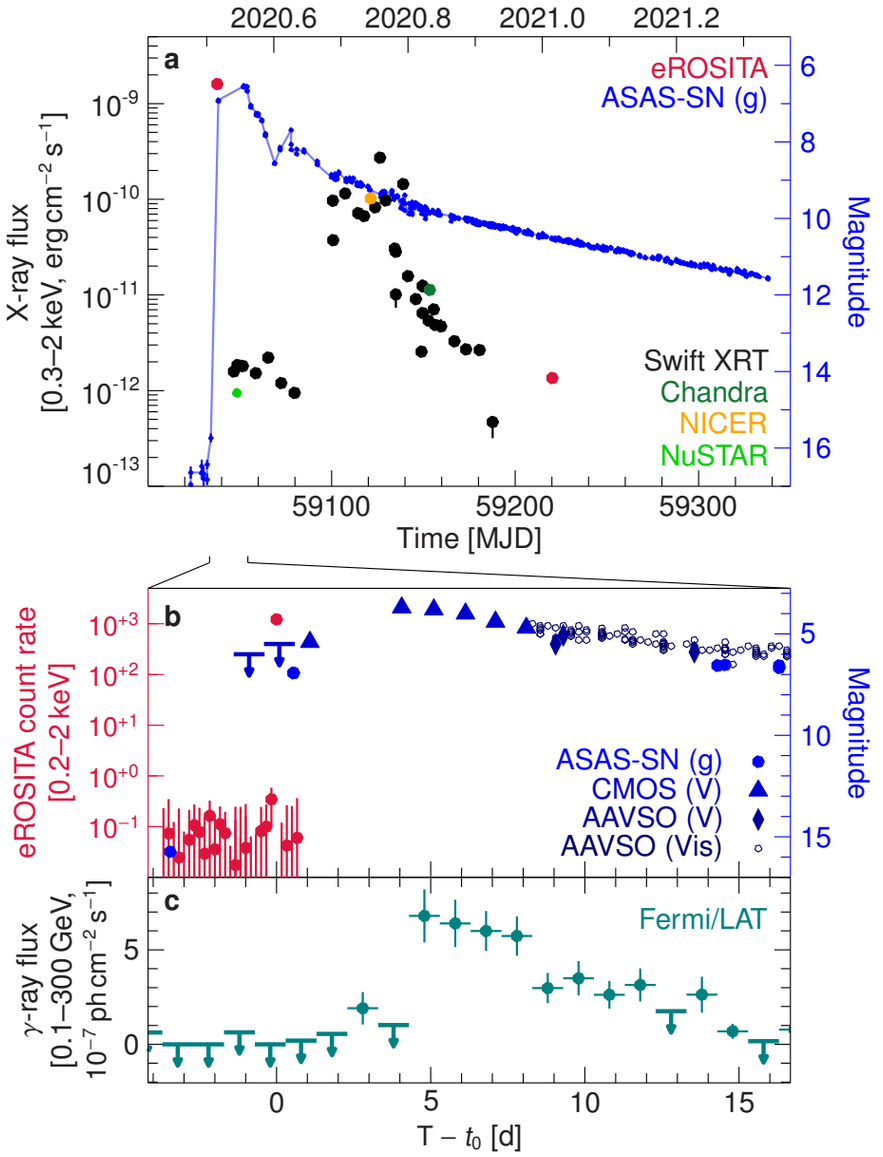
Novae

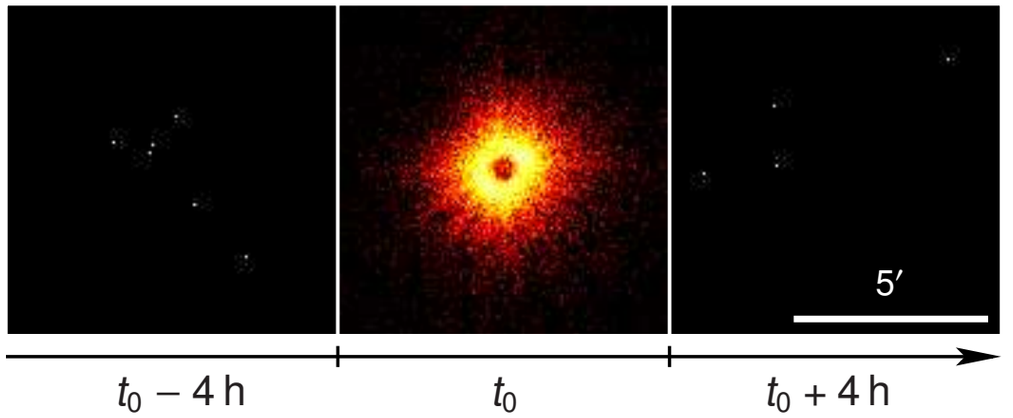


YZ Ret (Nova Reticuli 2020): Extremely bright (piled up) source seen on 2020-07-07, 16:47; no detection 4 h before and after

Novae

König et al. (2022, Nature)





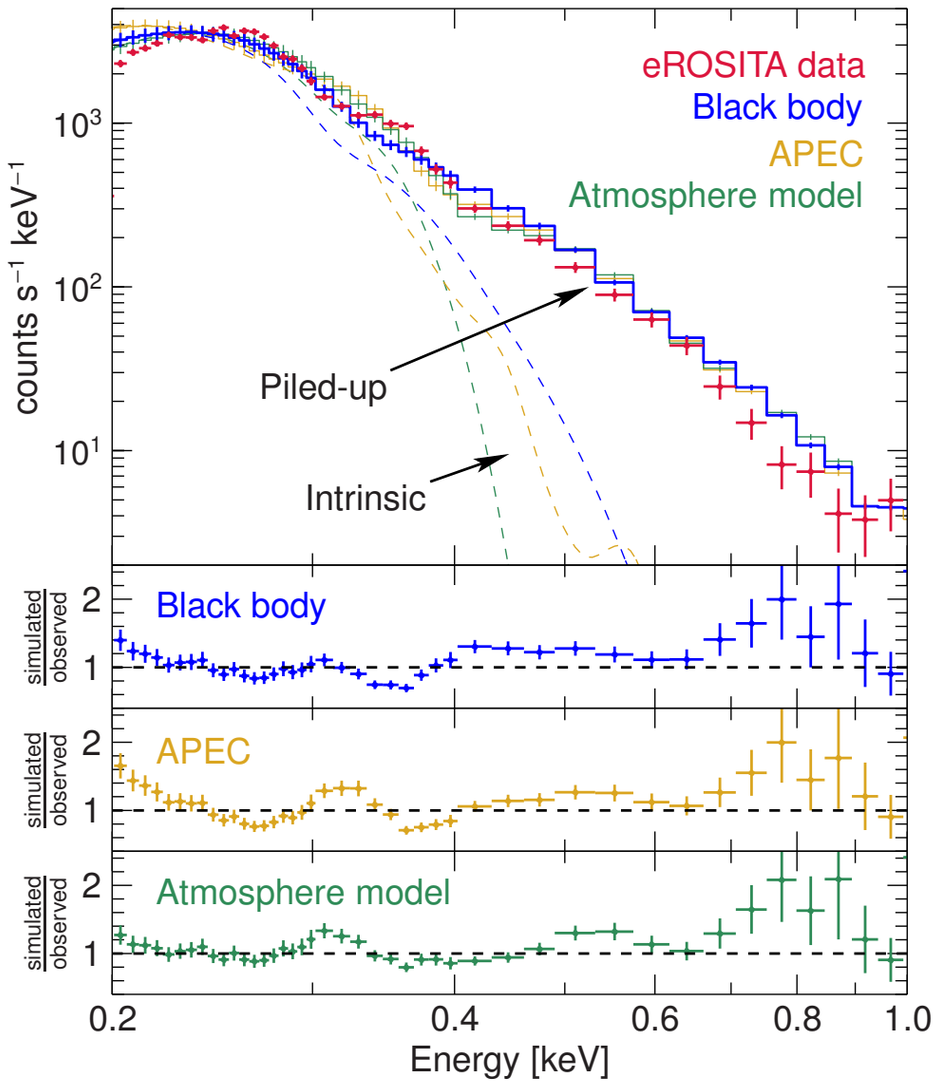
X-rays seen *before* optical brightening

First detection of X-ray flash of a nova.

30 years after prediction by Starrfield et al. (1990).

Novae

König et al. (2022, Nature)



Spectrum severely piled up

($F_{0.2-10\,\mathrm{keV}} = 1.86^{+0.38}_{-0.23} \times 10^{-8}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$)

Modeling: minimize SIXTE-end-to-end simulations of nova models, including pileup and vignetting effects:

- Black Body

  $\mathrm{kT} = 28.2^{+0.9}_{-2.8}\,\mathrm{eV}$, $\mathrm{L} = 2.0(1.2) \times 10^{38}\,\mathrm{erg\,s^{-1}}$, $\mathrm{R} = 50000 \pm 18000\,\mathrm{km}$

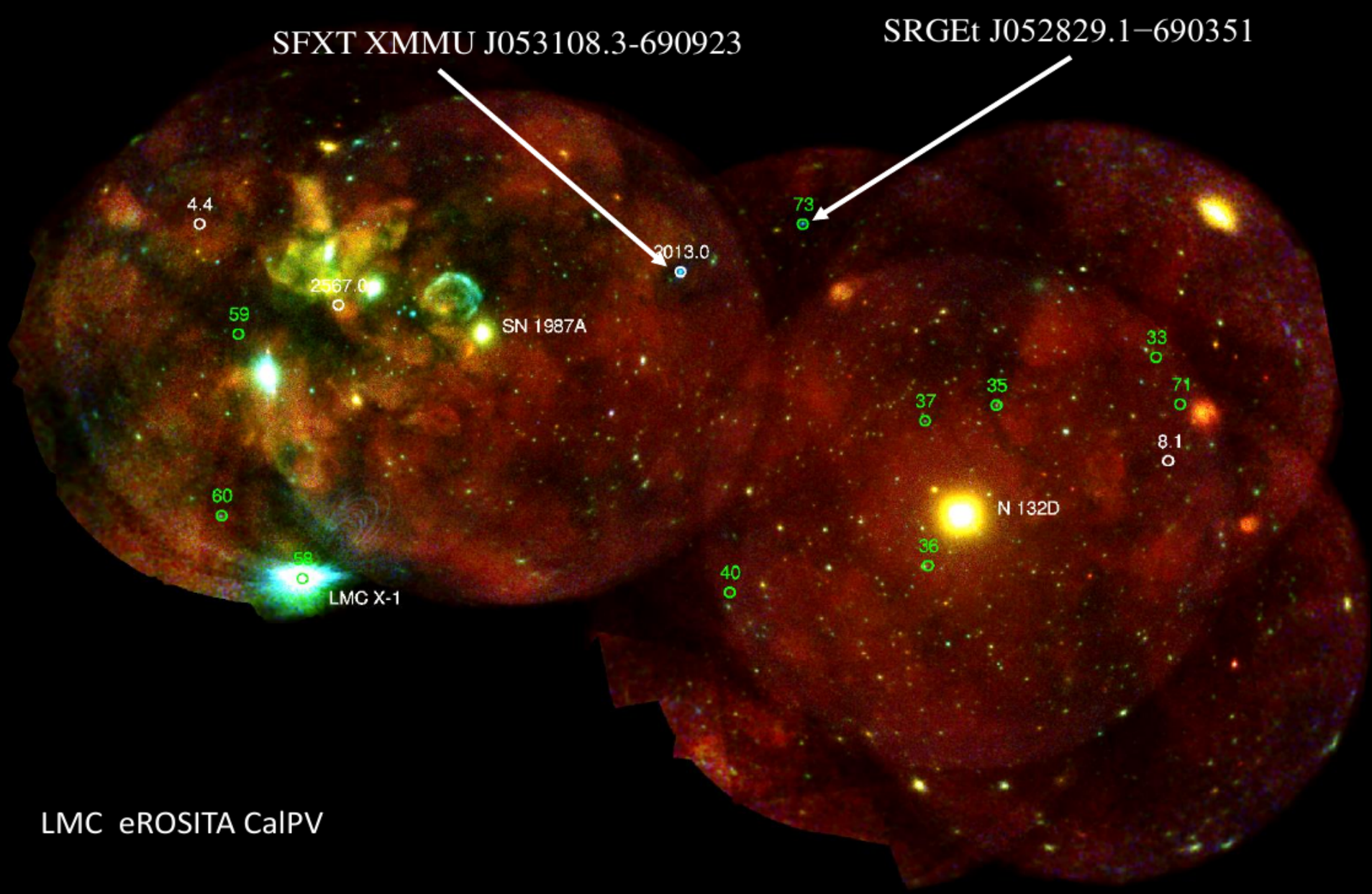
- NS atmosphere model

  $\mathrm{kT} = 27.1^{+1.2}_{-0.5}\,\mathrm{eV}$, $\mathrm{L} = 0.98(22) \times 10^{38}\,\mathrm{erg\,s^{-1}}$, $\mathrm{R} = 37000 \pm 2900\,\mathrm{km}$, $\log \mathrm{g} = 6.97 \pm 0.17$

Atmosphere model yields

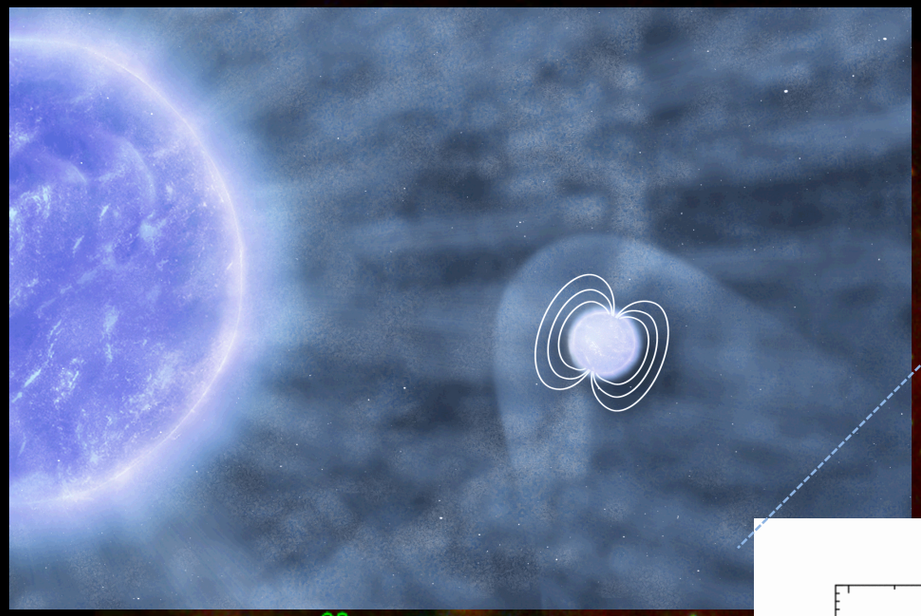
$M_{WD} = (0.98 \pm 0.23)\,M_\odot$

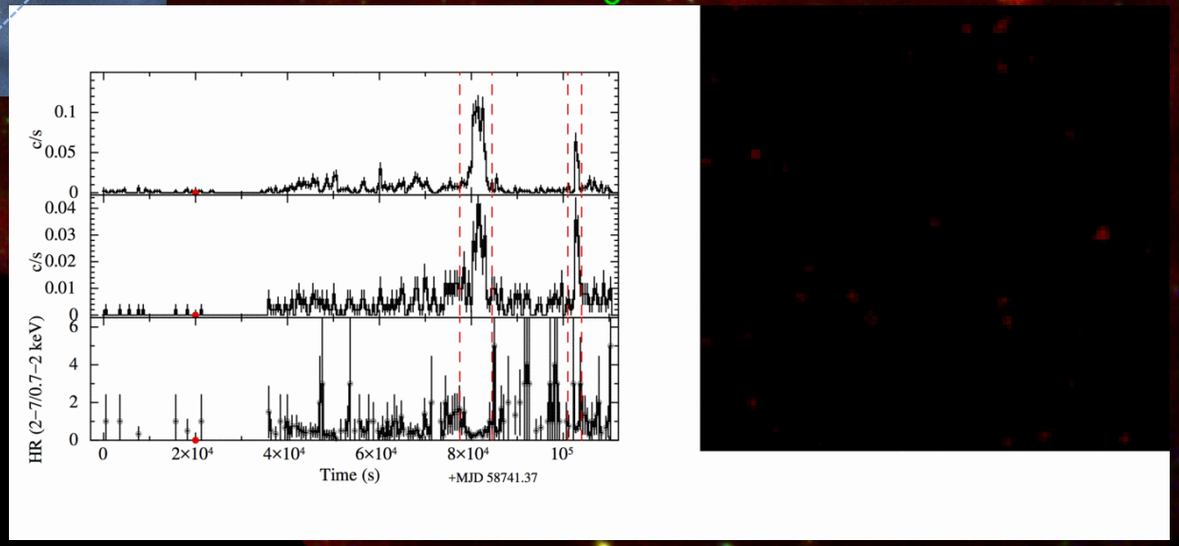
consistent with duration of X-ray flash; Hillman et al. (2014)


SFXT XMMU J053108.3-690923
SRGEt J052829.1−690351
4.4
73
2013.0
2567.0
59
SN 1987A
33
35
37
71
8.1
N 132D
60
36
40
58
LMC X-1
LMC eROSITA CalPV

F. Haberl

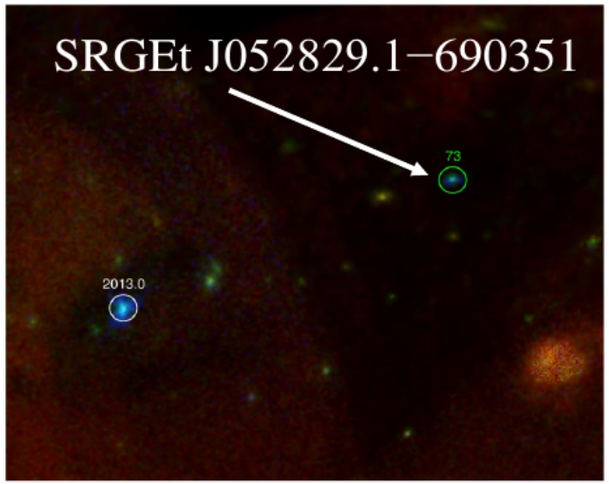
XMMU J053108.3−690923: the first direct evidence of a supergiant fast X-ray transient outside our galaxy



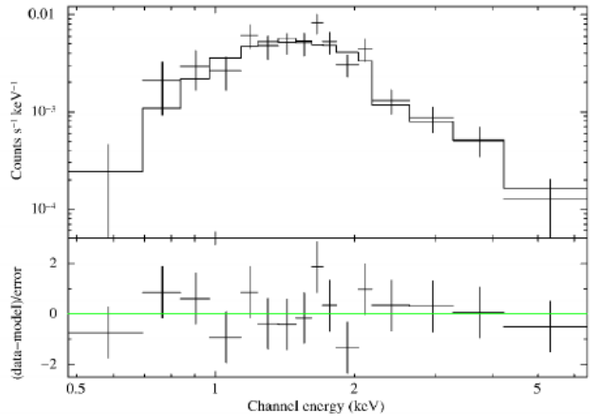


Maitra, Haberl, Vasilopoulos +21, A&A ,First science highlights from SRG/eROSITA

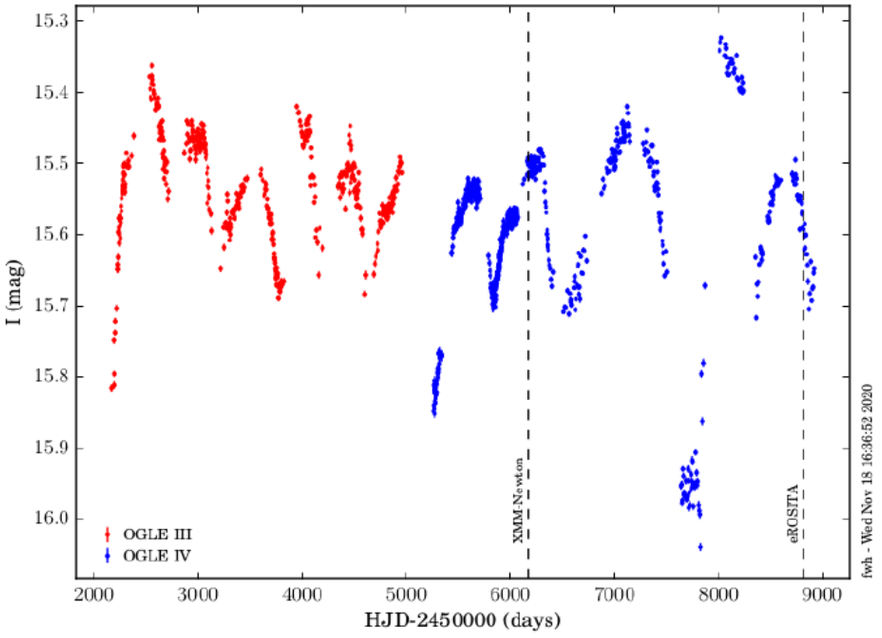
LMC



A new BeXRB transient in the LMC



eROSITA spectrum
Photon index = 0.68
$N_H = 7.3 \times 10^{21}$ H cm^{-2}
Flux (0.2-10 keV) =
4.8×10^{-13} erg/cm^2/s
Lx = 1.6×10^{35} erg/s



OGLE light curve from Sep. 2001 to March 2020

F. Haberl

Summary

eROSITA has already revolutionized our knowledge of the X-ray sky

- Survey is halfway there
- Science:
  - Galaxy Clusters
  - Evolution of Black Holes
  - Compact objects and stars in the Galaxy
  - Supernova Remnants
  - Transients