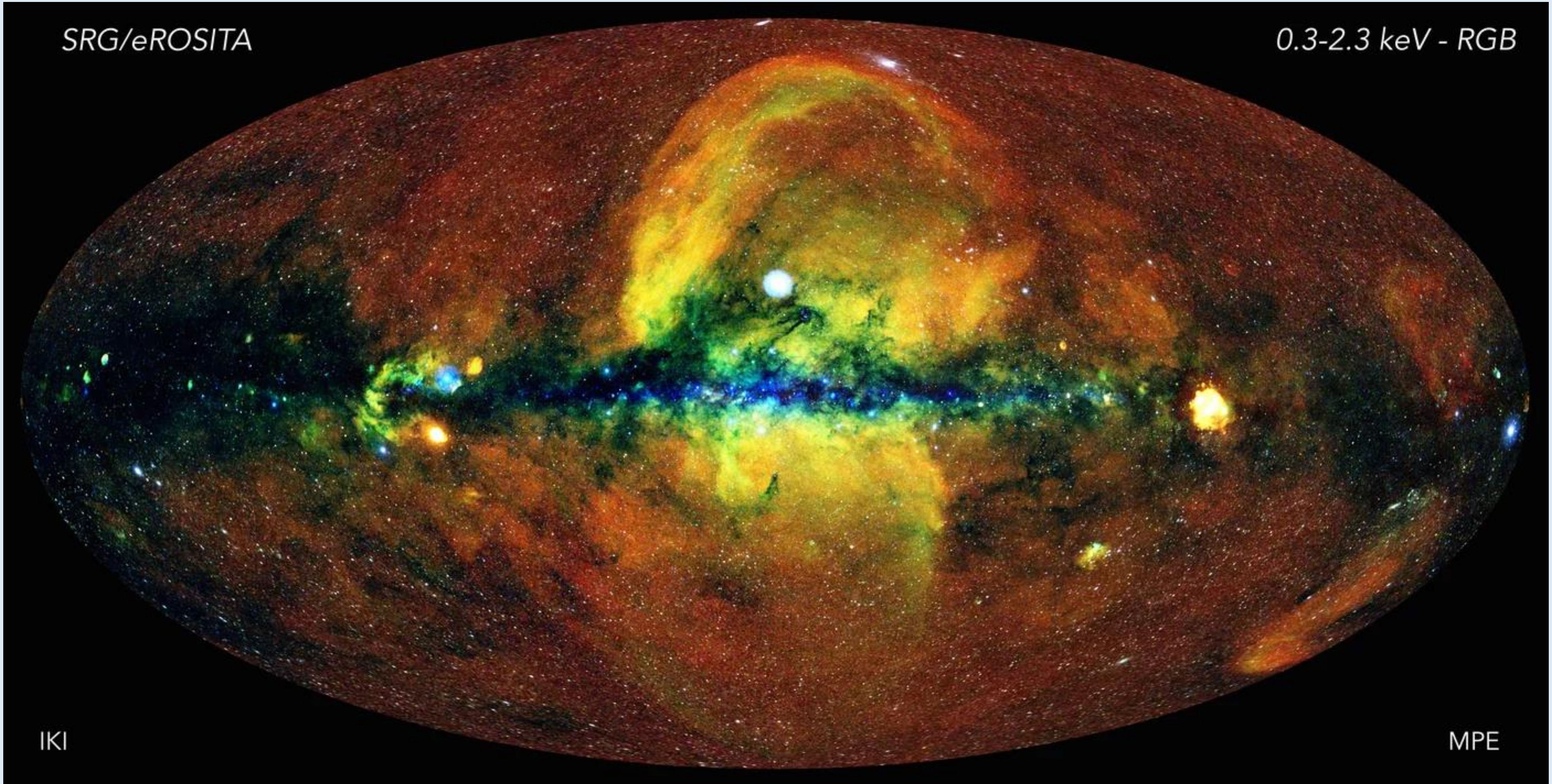
X-ray Astronomy with eROSITA



Outline

- Why observe in X-rays?
  - Galaxy clusters
- What is the eROSITA mission?
- Highlights from the eROSITA All-Sky Survey

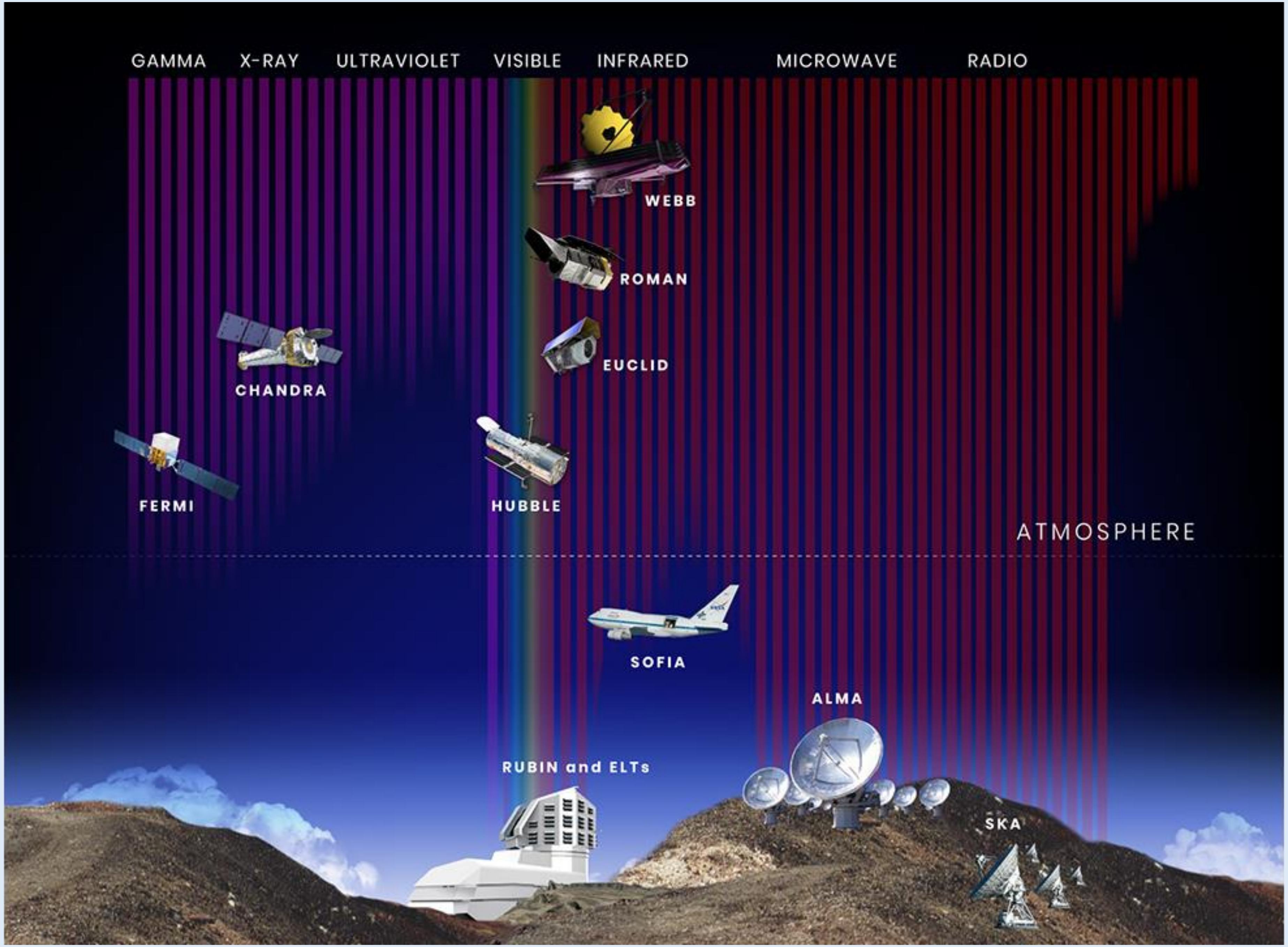
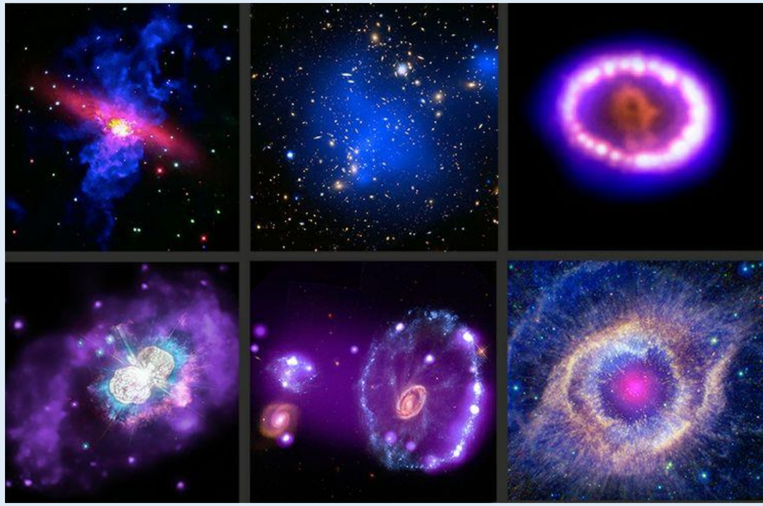


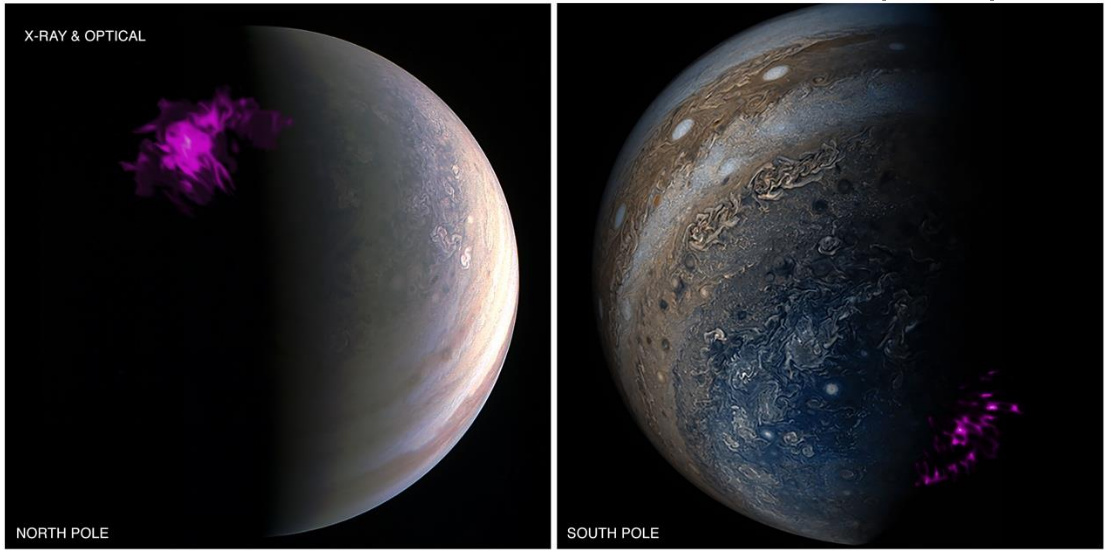
IMAGE:
NASA, STScI

X-ray come from the hottest and most violent places in the Universe

- Stars:
  - Being born, interacting, merging, dying
- Black holes:
  - Accreting material: Active Galactic Nuclei
- Galaxies and galaxy clusters
  - Very hot gas, >million Kelvin
- Planets
  - Jupiter's aurorae



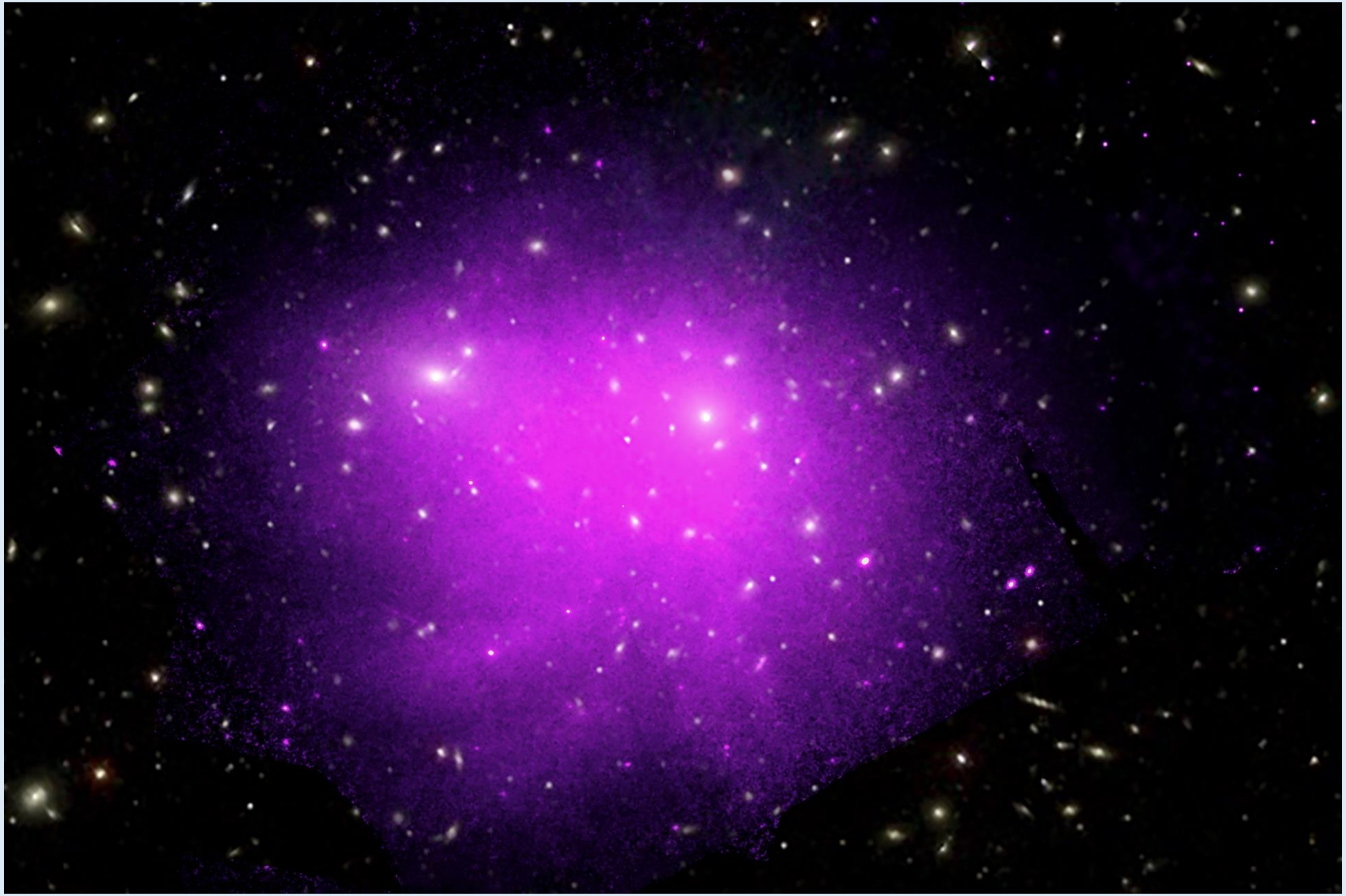
Credit: NASA/CXC/SAO



Credit: NASA/CXC/M.Weiss

Galaxy Clusters

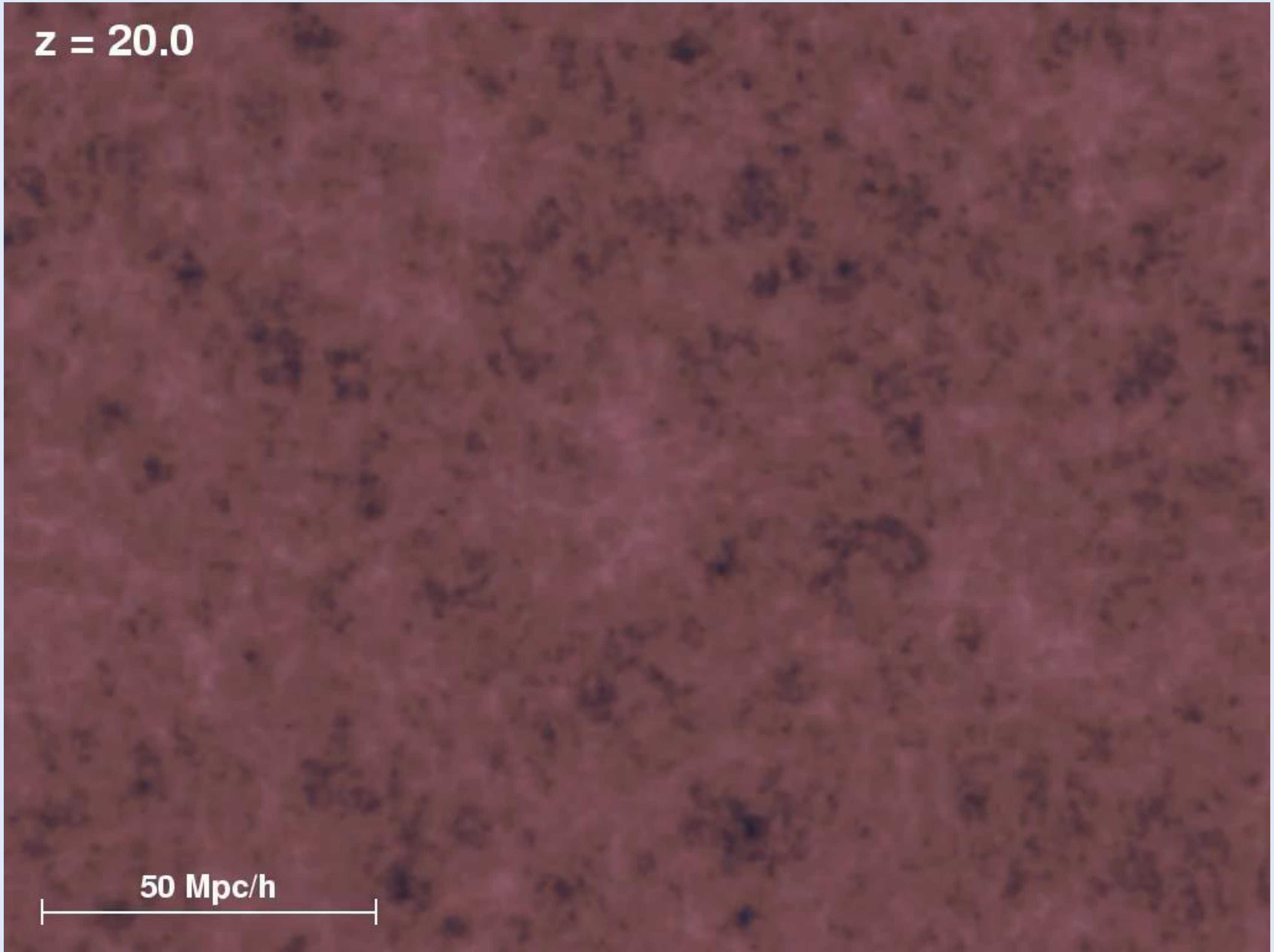
- Largest structures to form in the Universe
- X-ray glow from hot gas filling the cluster (100 million K)
- 5x as much mass in gas as in all galaxies in the cluster



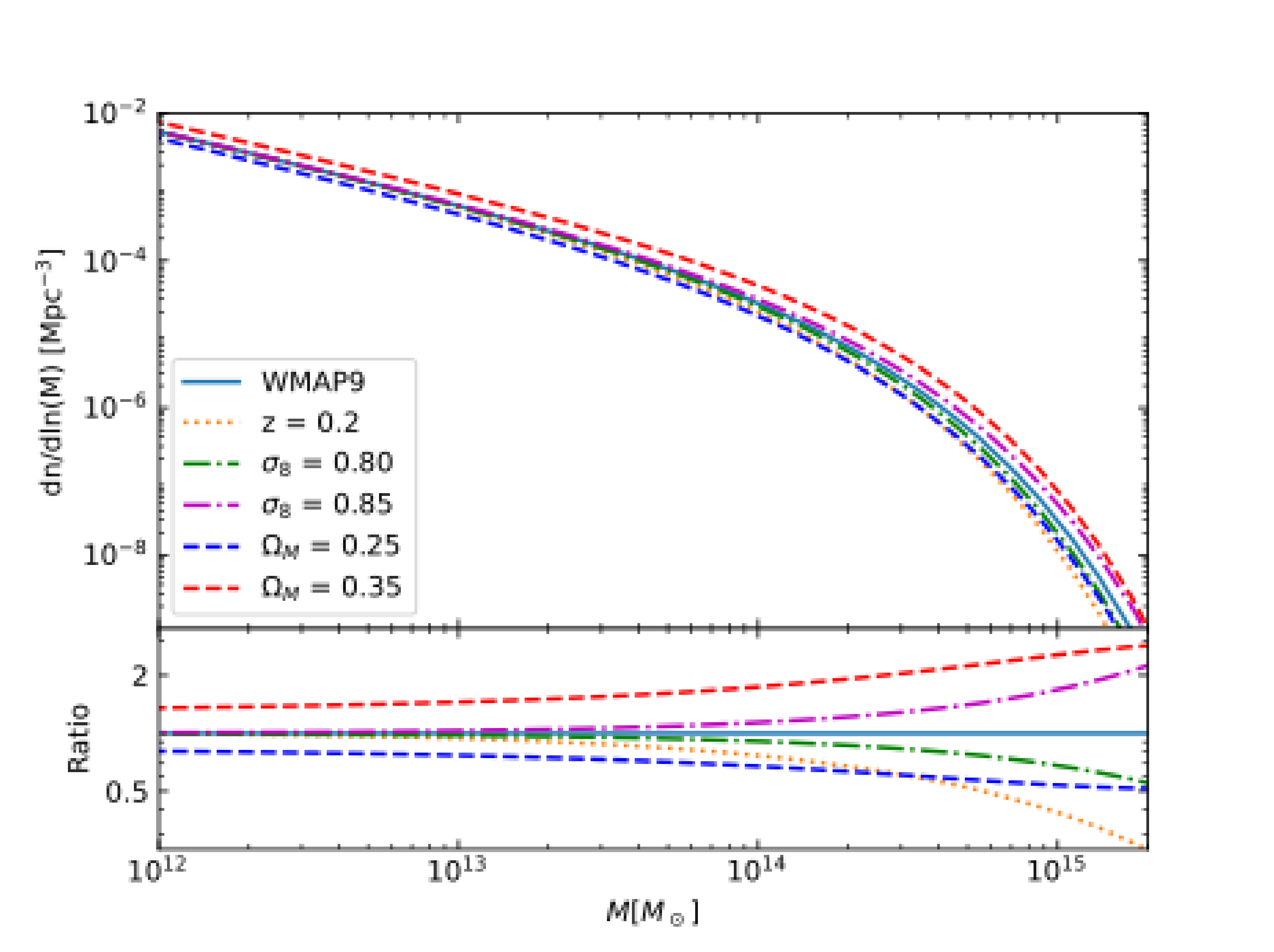
Why Study Galaxy Clusters?

- Cluster Cosmology
- Astrophysical processes
- Dark Matter

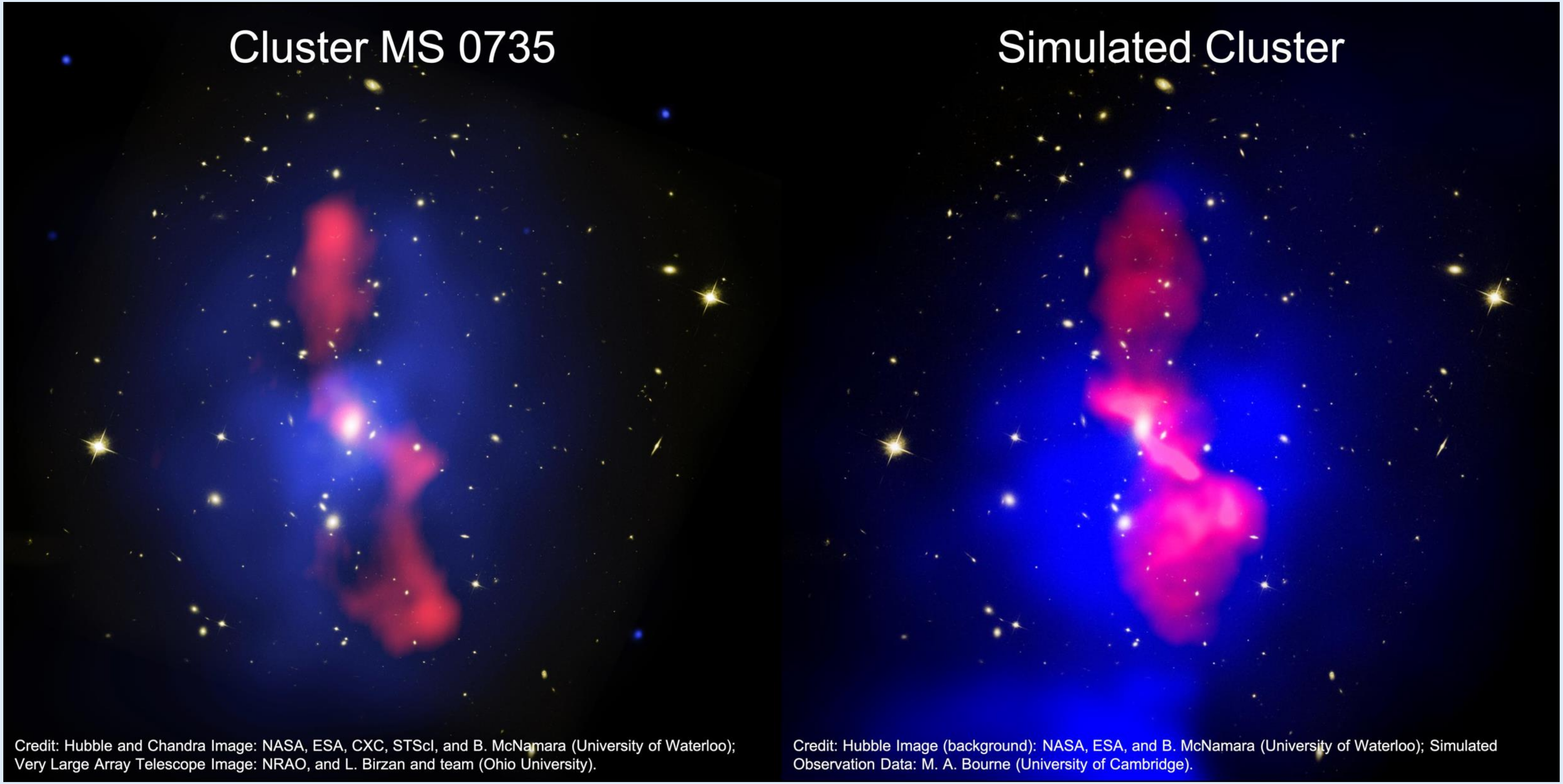
Cluster Cosmology



Cluster Cosmology



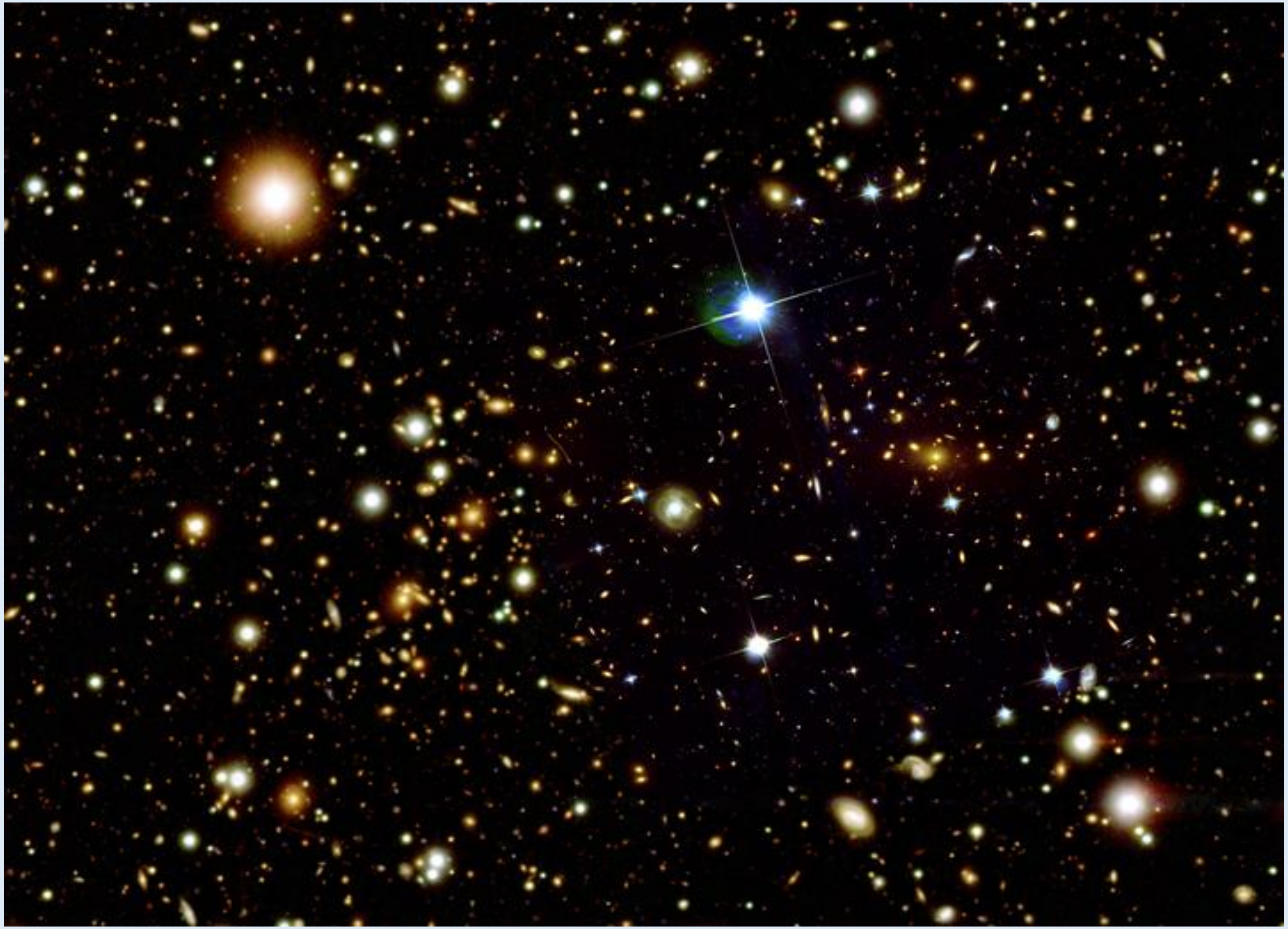
Astrophysical processes



Credit: Hubble and Chandra Image: NASA, ESA, CXC, STScI, and B. McNamara (University of Waterloo); Very Large Array Telescope Image: NRAO, and L. Birzan and team (Ohio University).

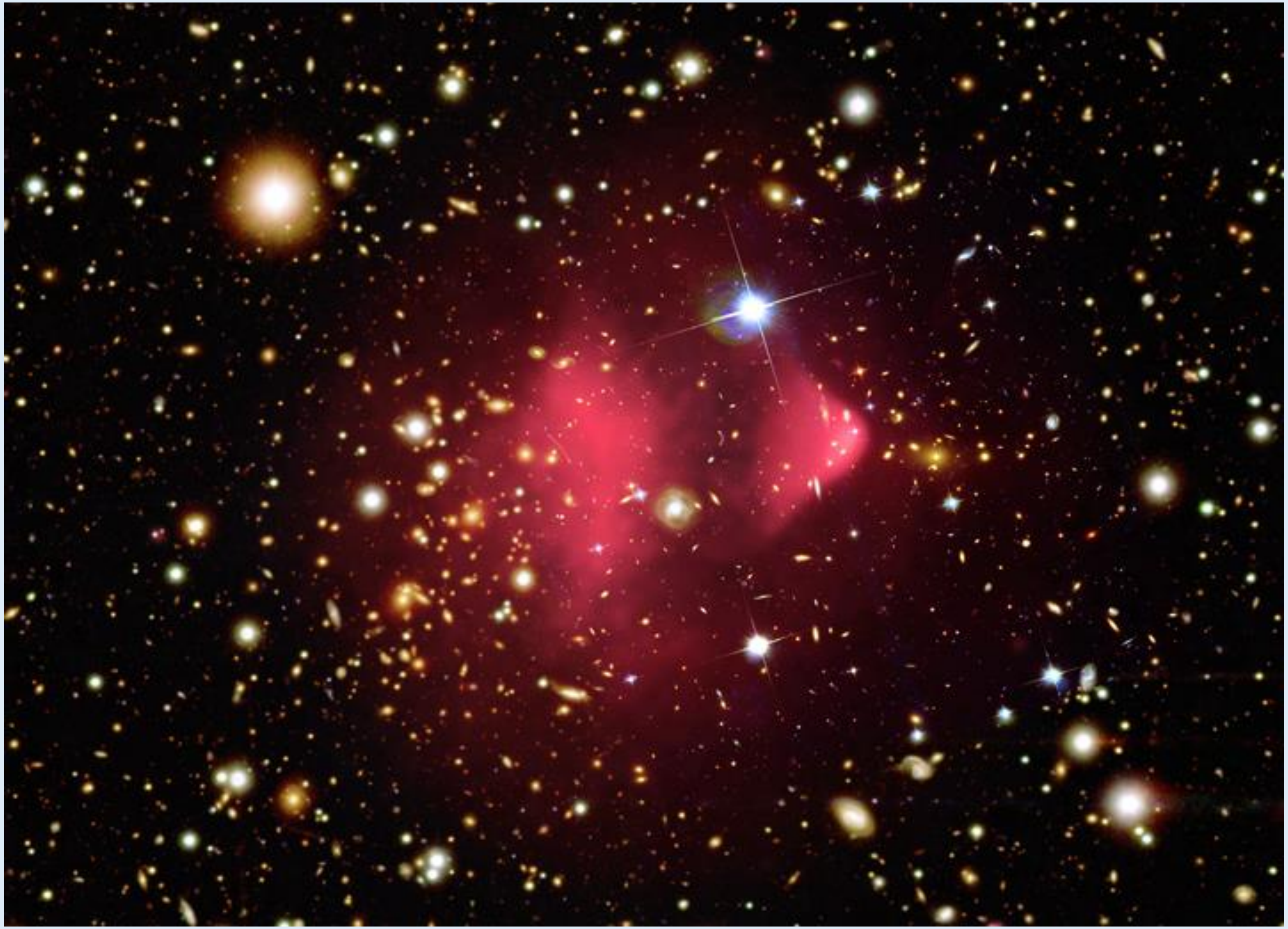
Credit: Hubble Image (background): NASA, ESA, and B. McNamara (University of Waterloo); Simulated Observation Data: M. A. Bourne (University of Cambridge).

Dark Matter – Bullet Cluster



Clowe+ (2006)

Dark Matter – Bullet Cluster



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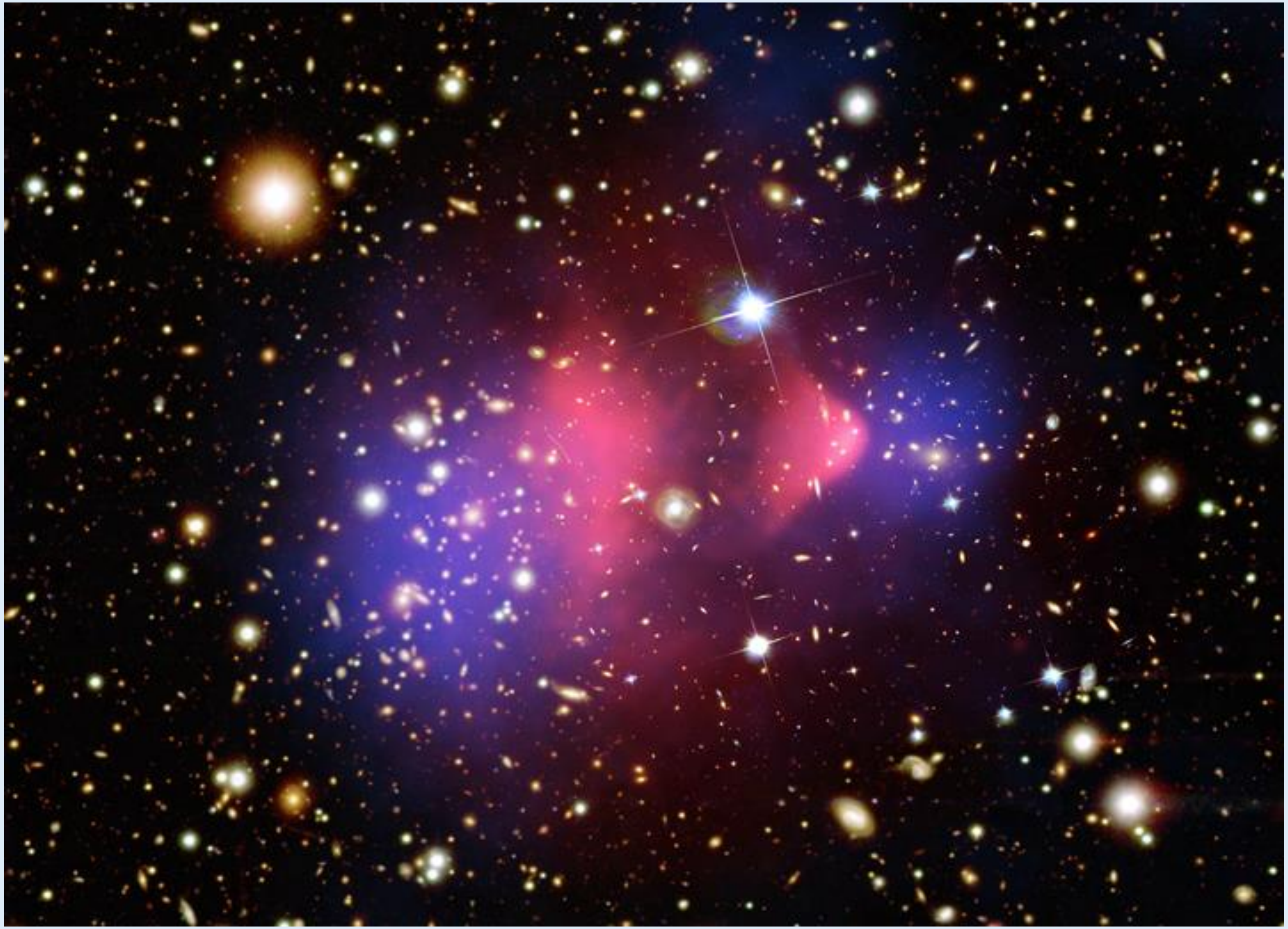
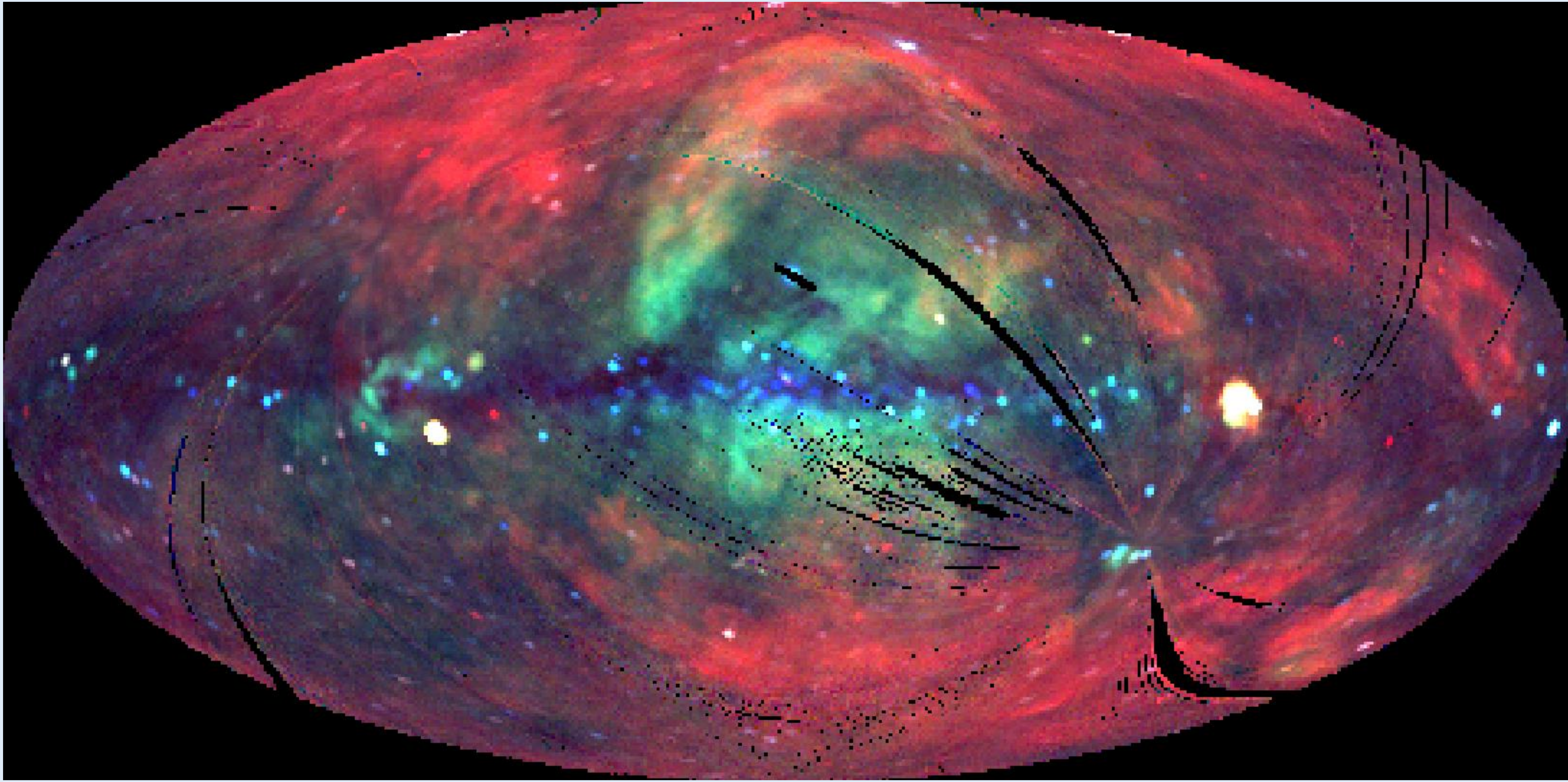


Clowe+ (2006)

A very brief history of X-ray Instruments

- <1960s detections of Solar X-rays using rockets
- 1962 – first none solar detection Scorpius X-1
- 1970 – first X-ray satellite: Uhuru detected 339 sources
- 1978 – Einstein Observatory: first images of X-ray sources
- 1990 – ROSAT: all-sky survey
- 1999 – Chandra: NASA high resolution
- 1999 – XMM-Newton: ESA large field of view

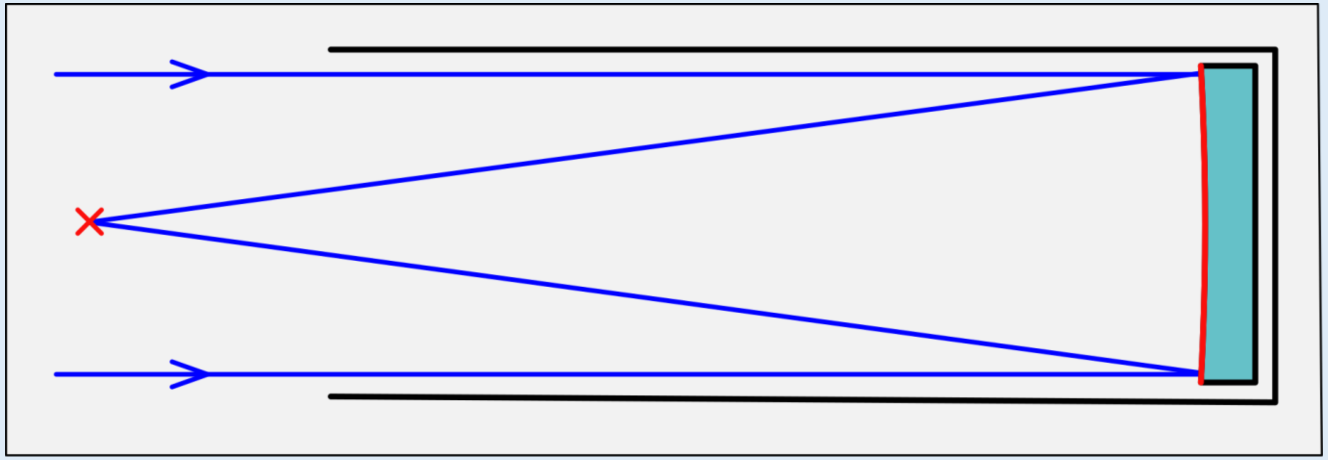


Credit: Max-Planck-Institut für extraterrestrische Physik (MPE) and S. L. Snowden

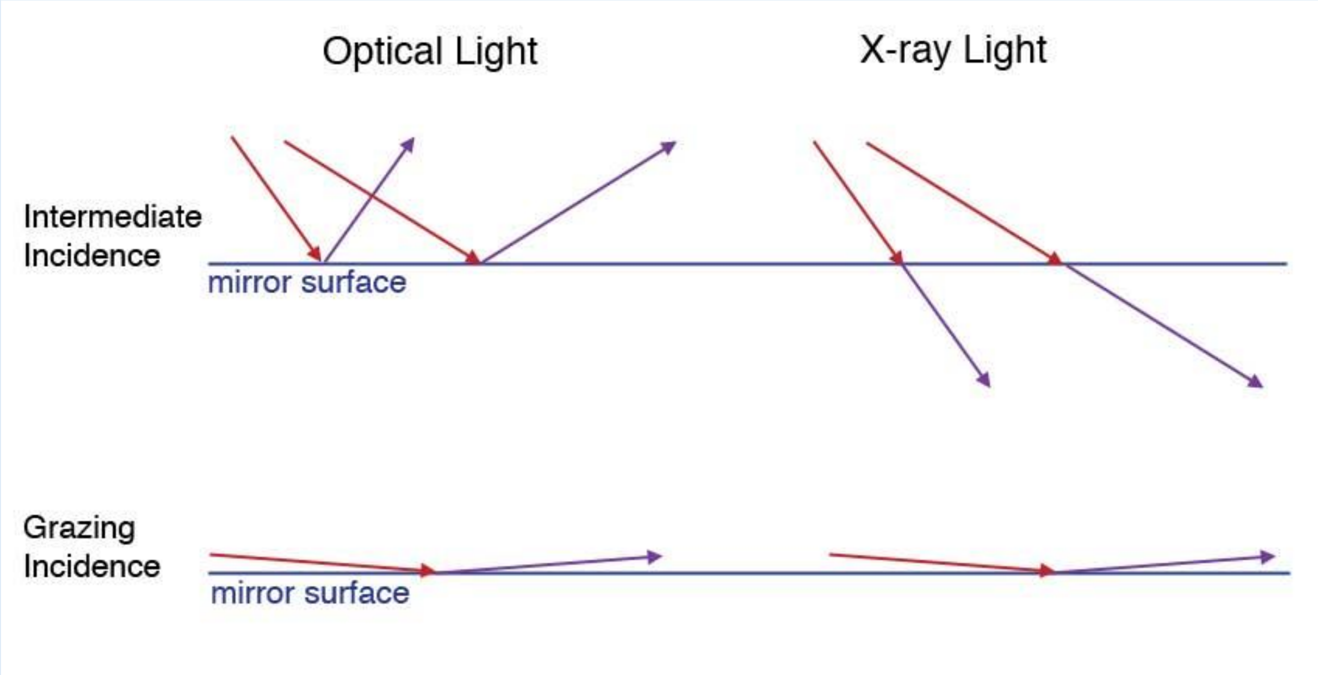
Max-Planck-Institut für extraterrestrische Physik (MPE)

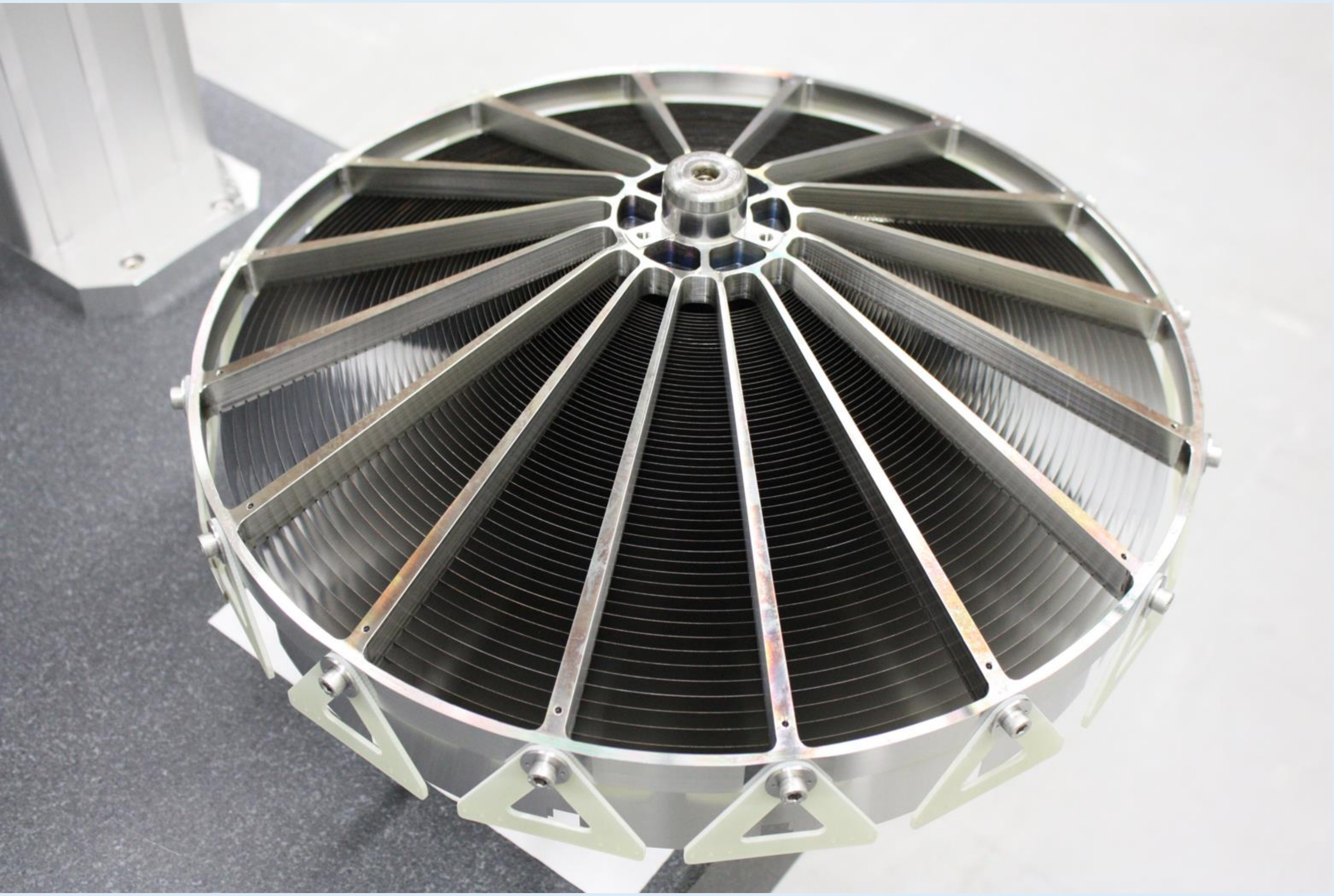
How do we observe X-rays?

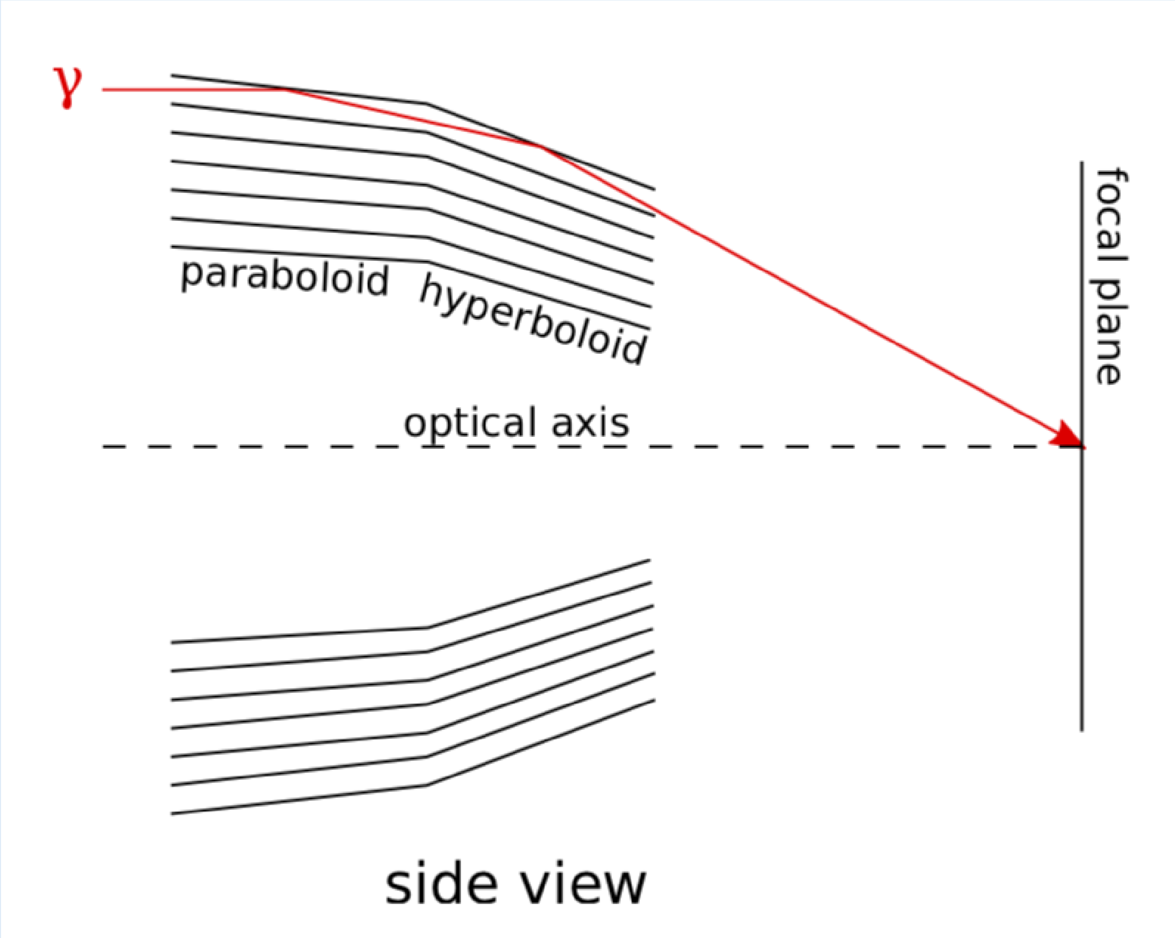
Optical telescope ->



- For X-ray light mirrors we need grazing incidence reflection

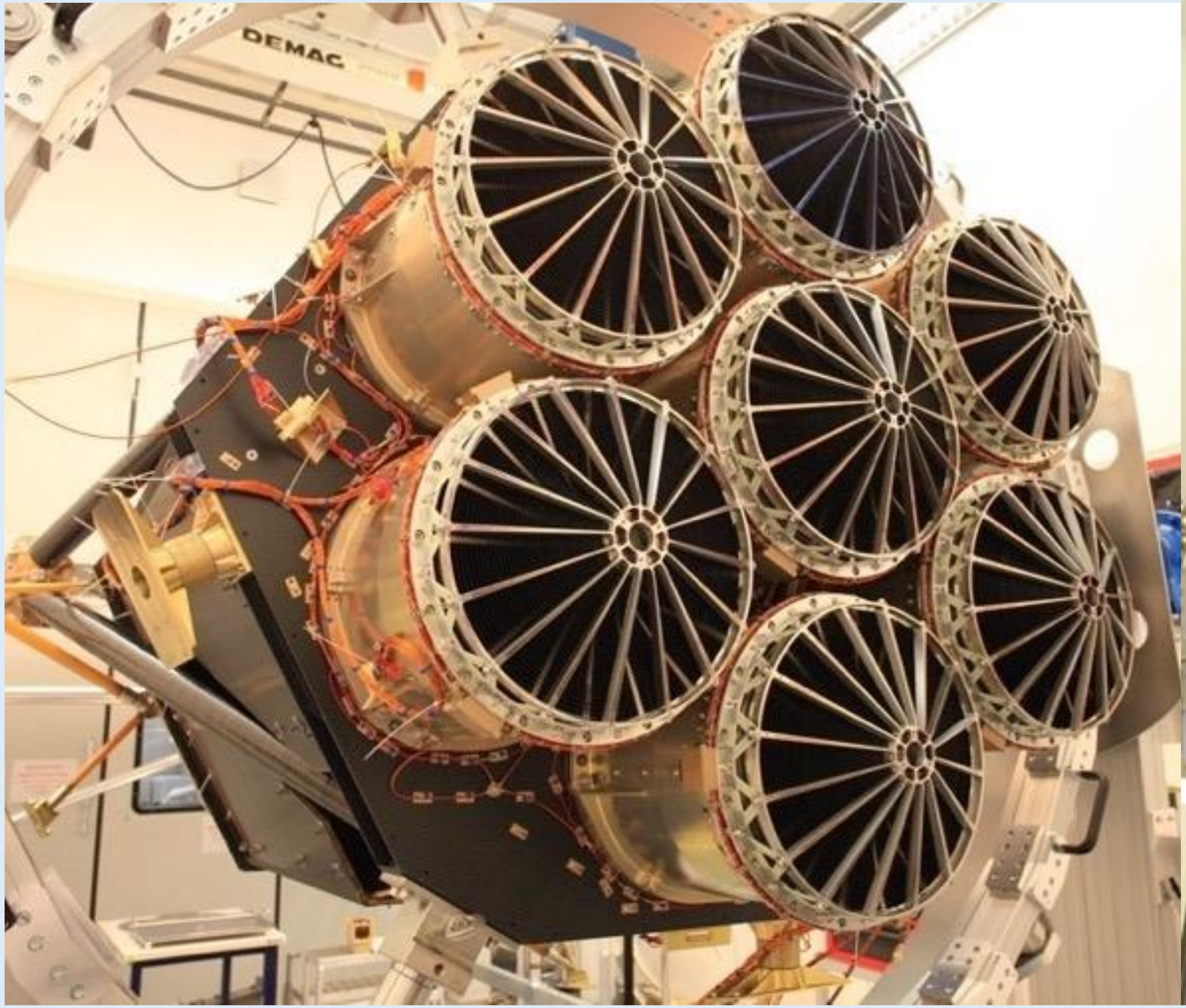


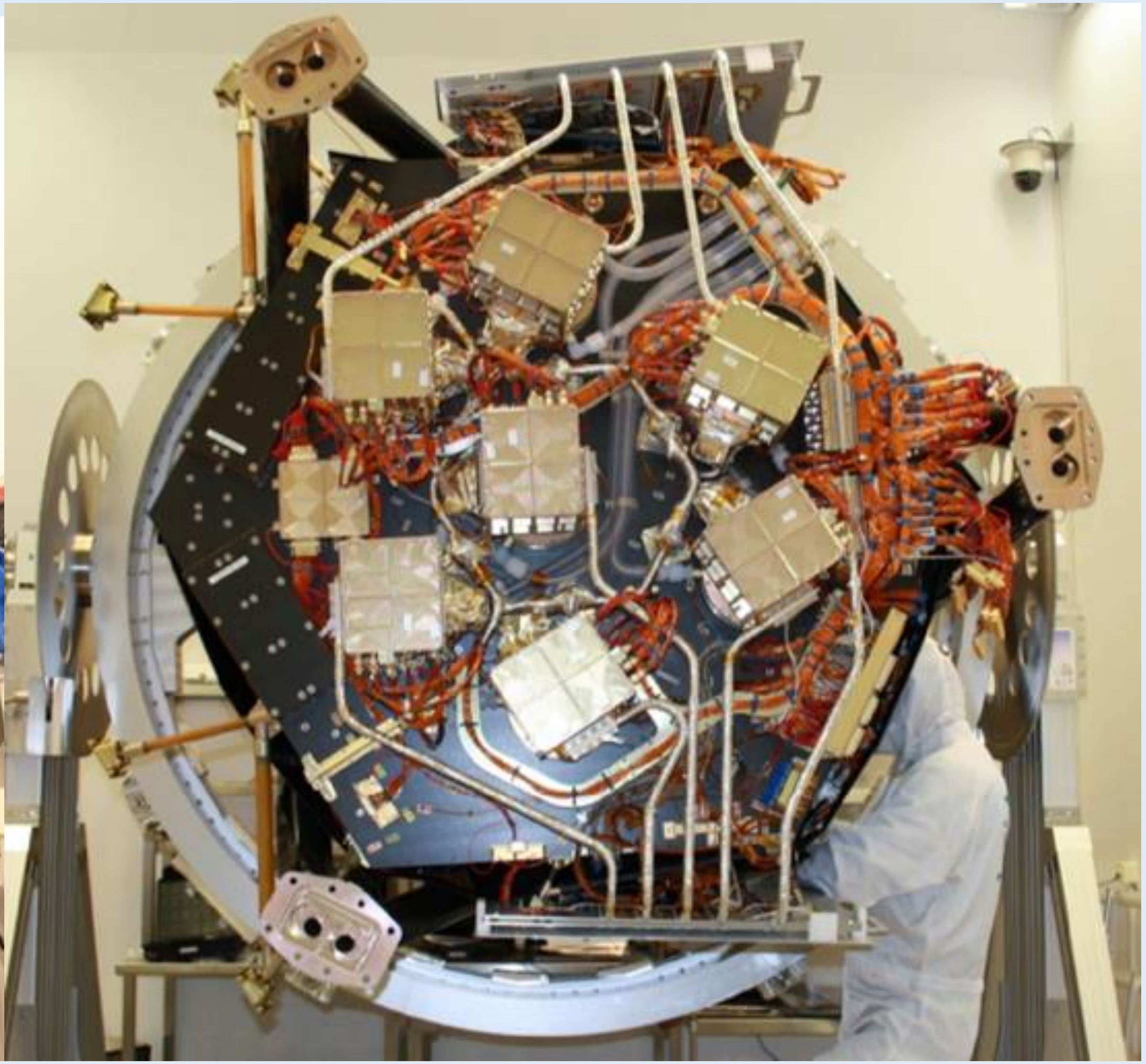




Max-Planck-Institut für extraterrestrische Physik (MPE)

eROSITA on SRG [Predehl+ 2021; Sunyaev+ 2021]

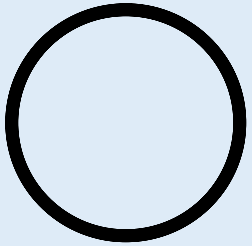




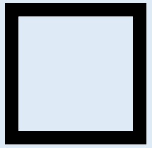
eROSITA's advantage:
large Field of View and Grasp

Moon diameter
30 arcmin

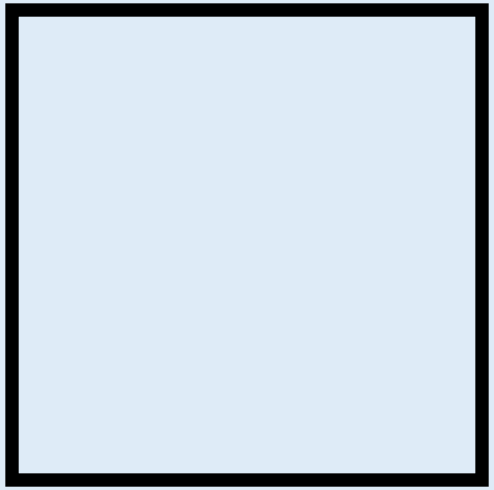
XMM-Newton
Field of view ~ 30 arcmin



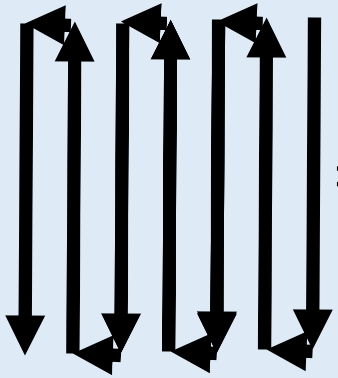
Chandra
Field of view ~ 17 arcmin



eROSITA
Field of view ~ 62 arcmin

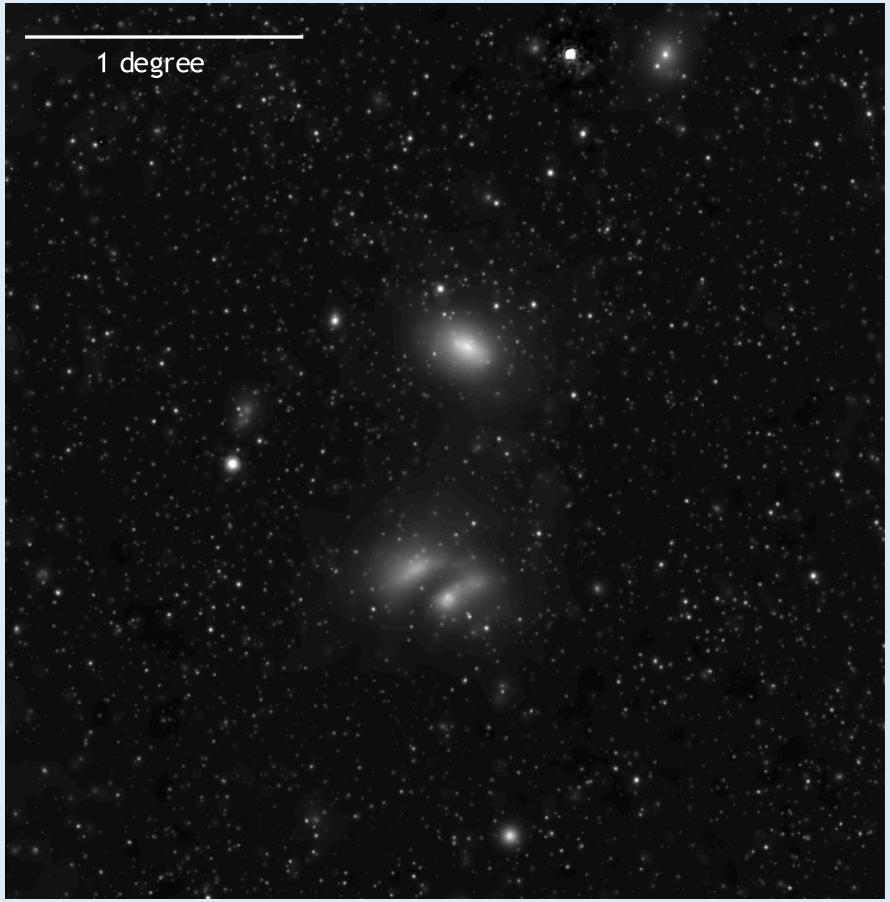


+



Scanning feature

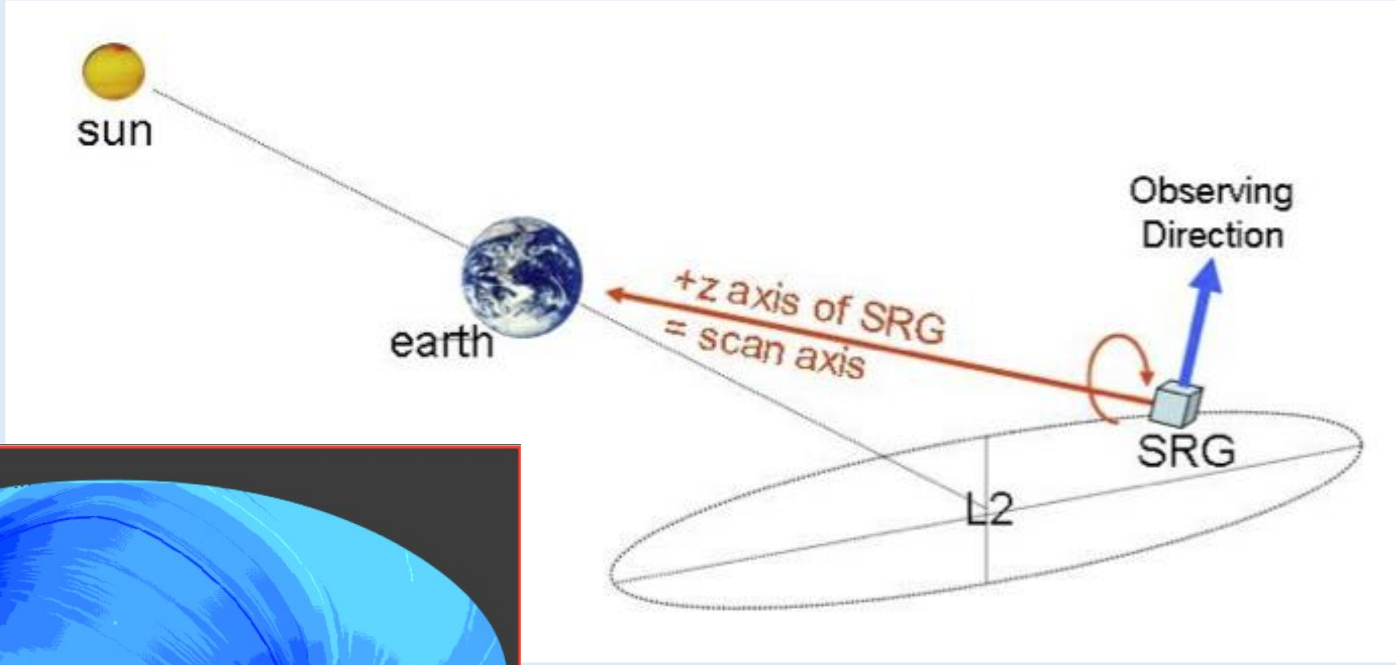
=

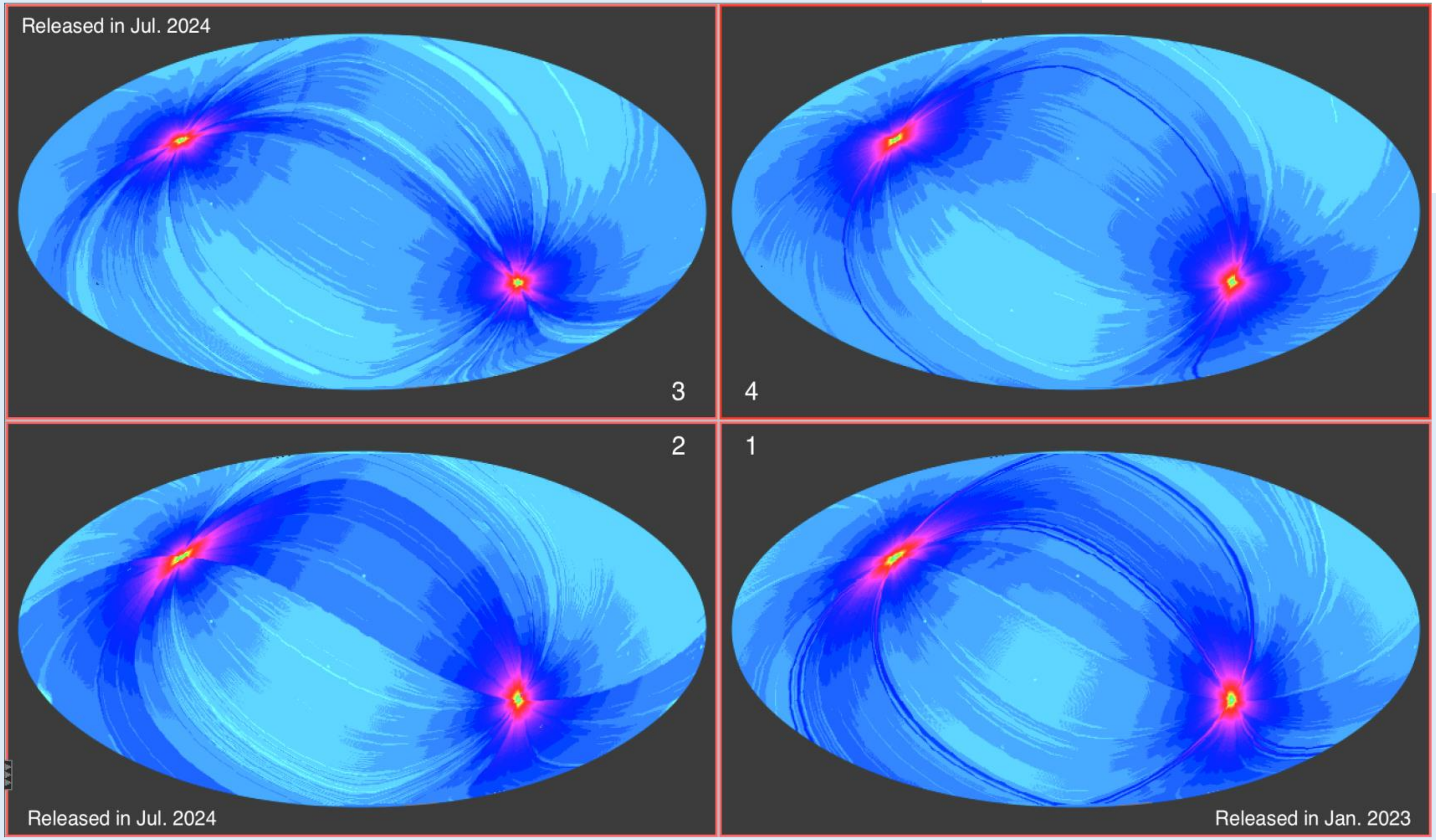


3 Observing modes:
continuous scan (survey), field scan, pointing

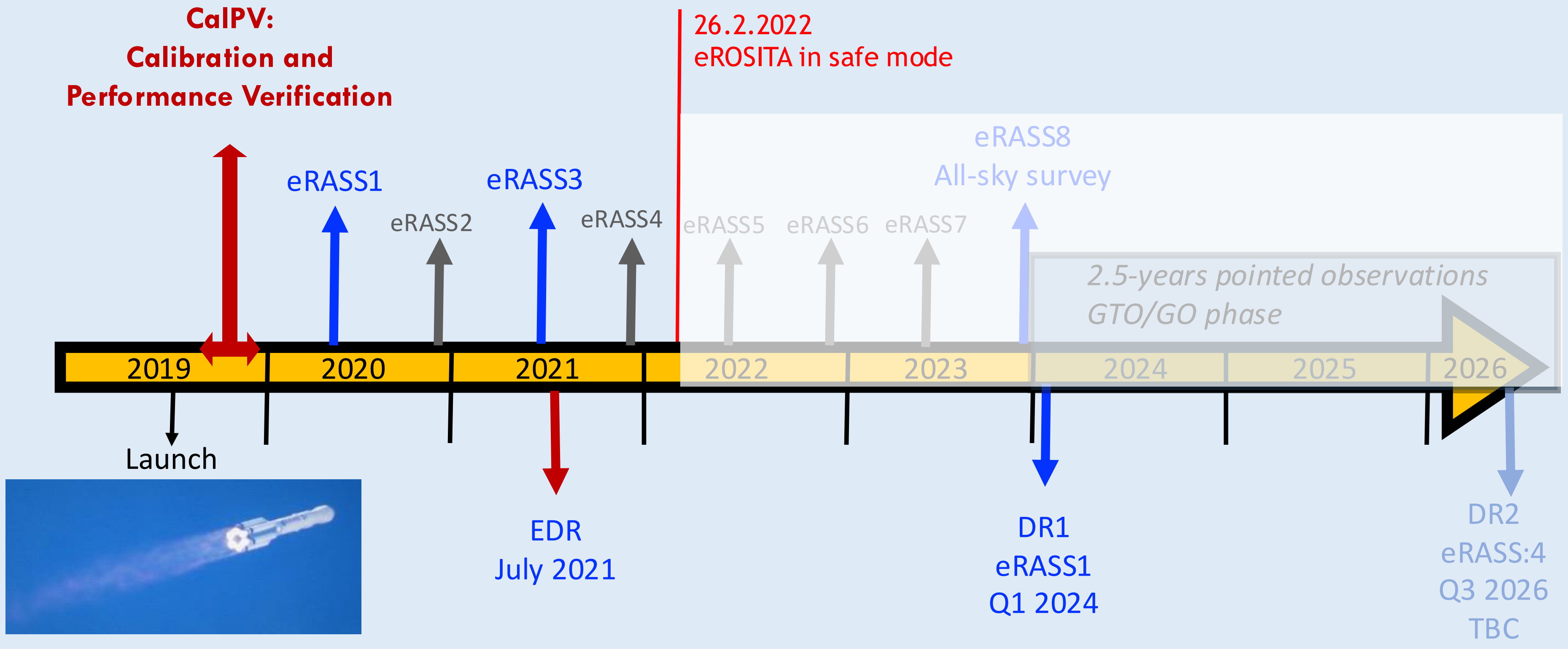
SRG/eROSITA 0.2-2 keV image of
A3391/3395
(Reiprich et al. 2021)

Scanning mode

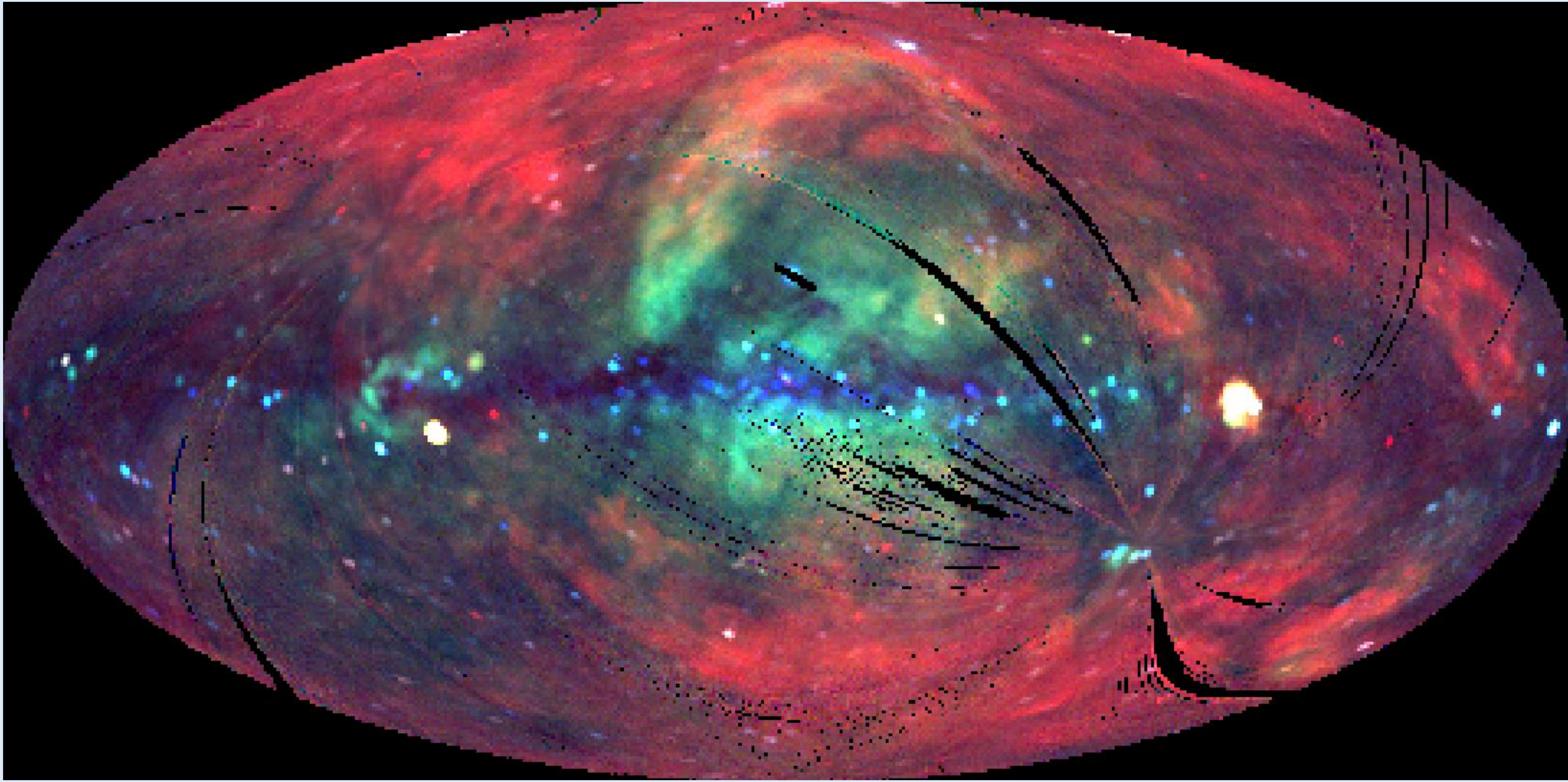




Predehl+ 2021



- Early Data Release (EDR) in 2021: several fields, including eFEDS mini-survey
- DR1 on 31.1.2024
- DR2 (eRASS:3 catalog) ~ mid-2026
- DR3 (all eRASS:5 data) ~ mid-2028 (TBC)



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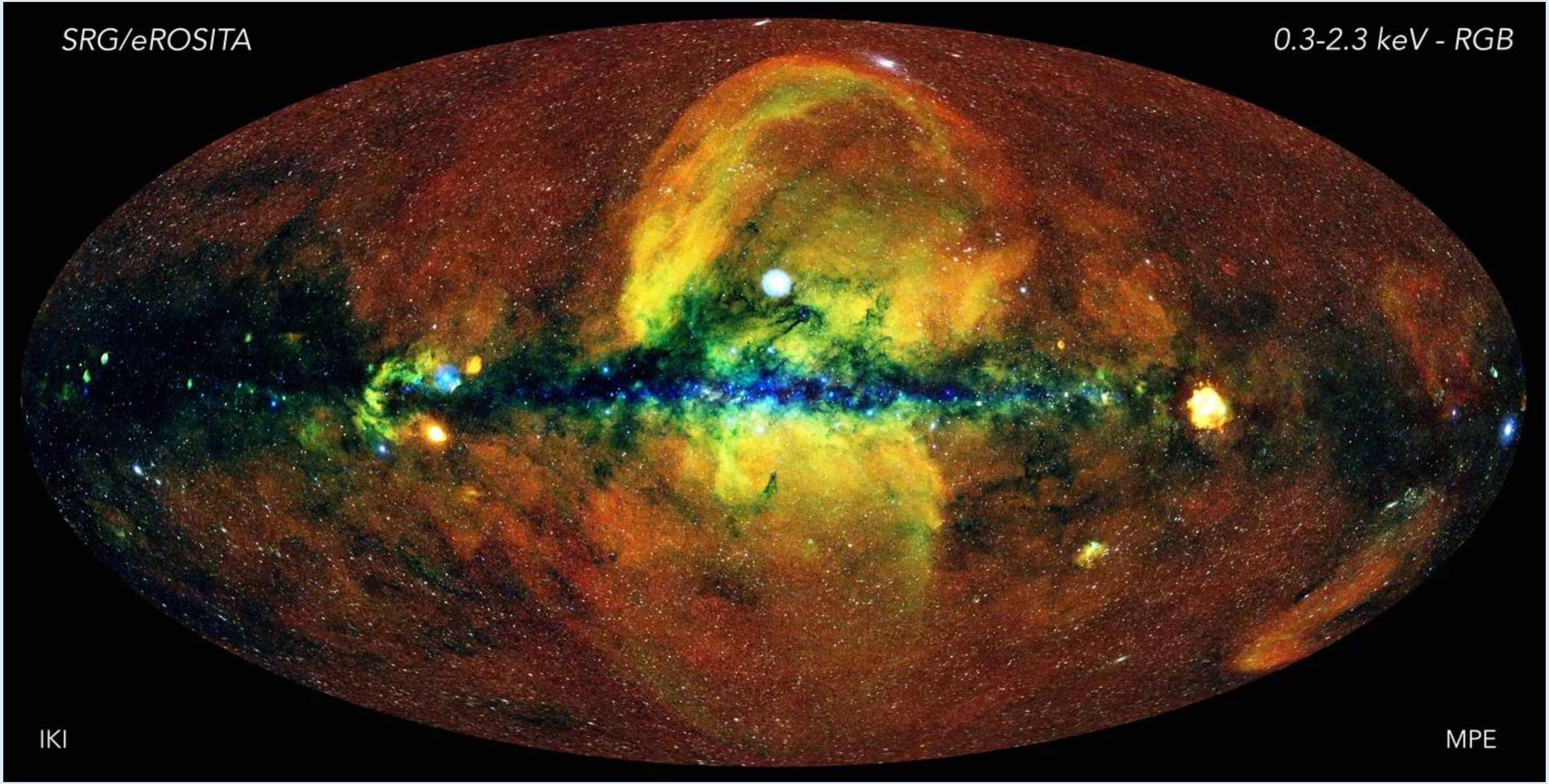
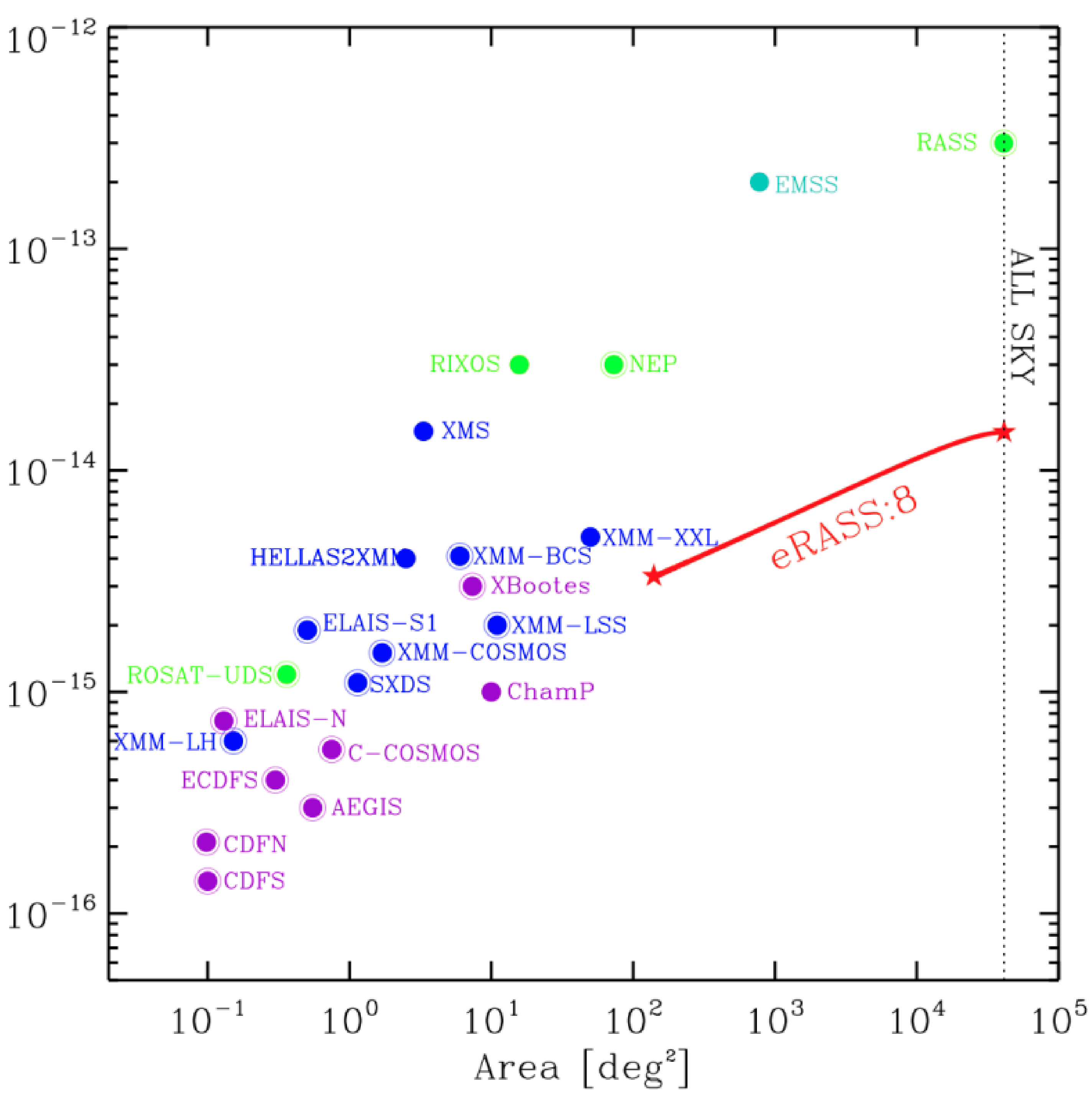

SRG/eROSITA
0.3-2.3 keV - RGB
IKI
MPE

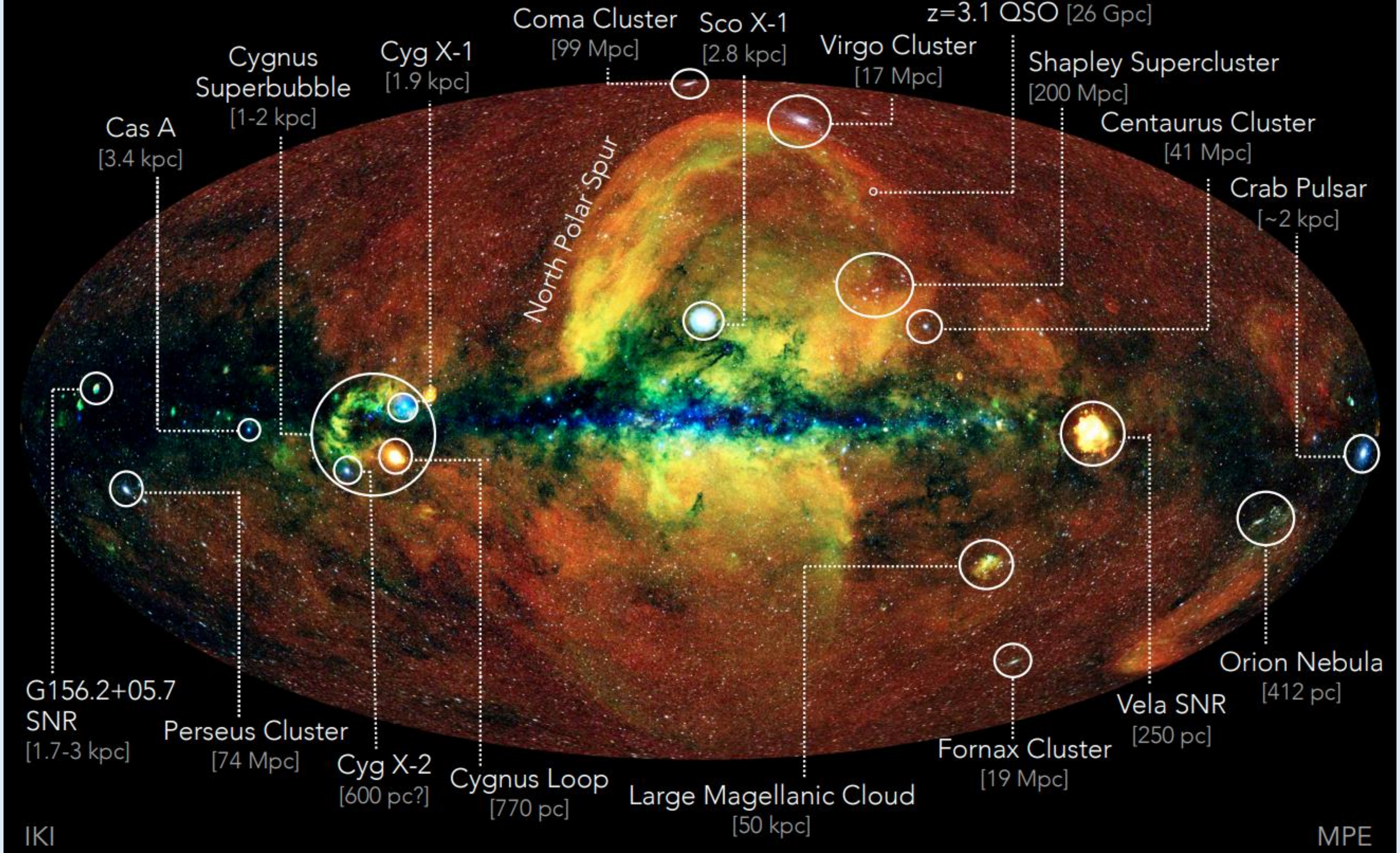
The eROSITA All-Sky Surveys by Numbers

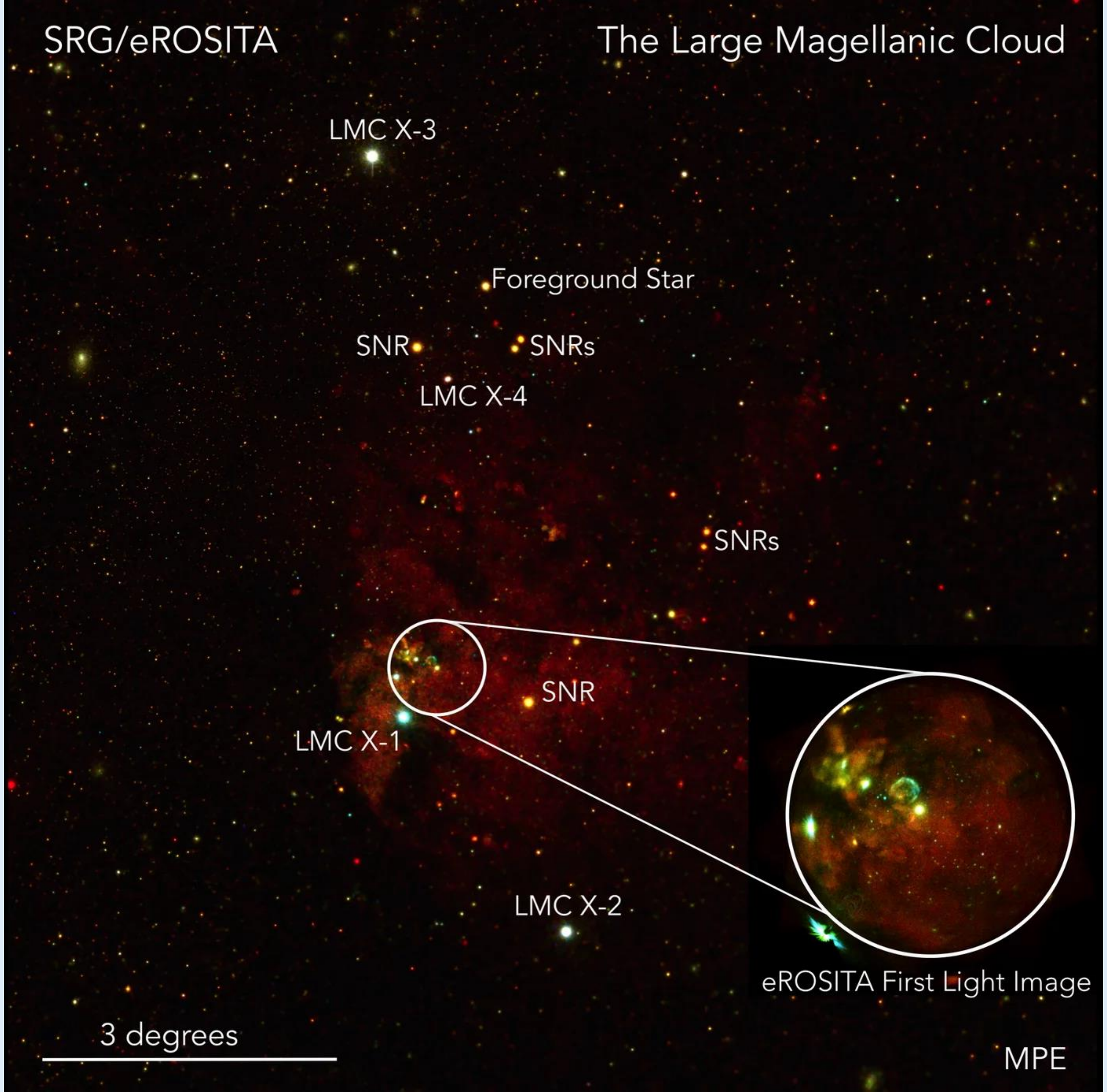
- Completed 4 all-sky survey (12/2019 – 12/2021)
- **~1.6 Billion** 0.2-5keV calibrated photons (~350 Gb telemetry)
- Typical (point-source) sensitivity:
  - Single pass (eRASS1,2,3,4)
    - ~5×10^{-14} erg/s/cm^2 [0.2-2.3 keV]; **4-5x deeper than RASS**
    - ~7×10^{-13} erg/s/cm^2 [2.3-5 keV]
  - Cumulative (eRASS:4)
    - ~2×10^{-14} erg/s/cm^2 [0.2-2.3 keV]
    - ~2×10^{-13} erg/s/cm^2 [2.3-5 keV]
- eRASS1 (half-sky): 0.9M point sources ~doubles the number of known X-ray sources! 26k extended, ~12k confirmed clusters
- eRASS:5 (half-sky; preliminary): 3.1M point sources; 87k extended; ~45k confirmed clusters



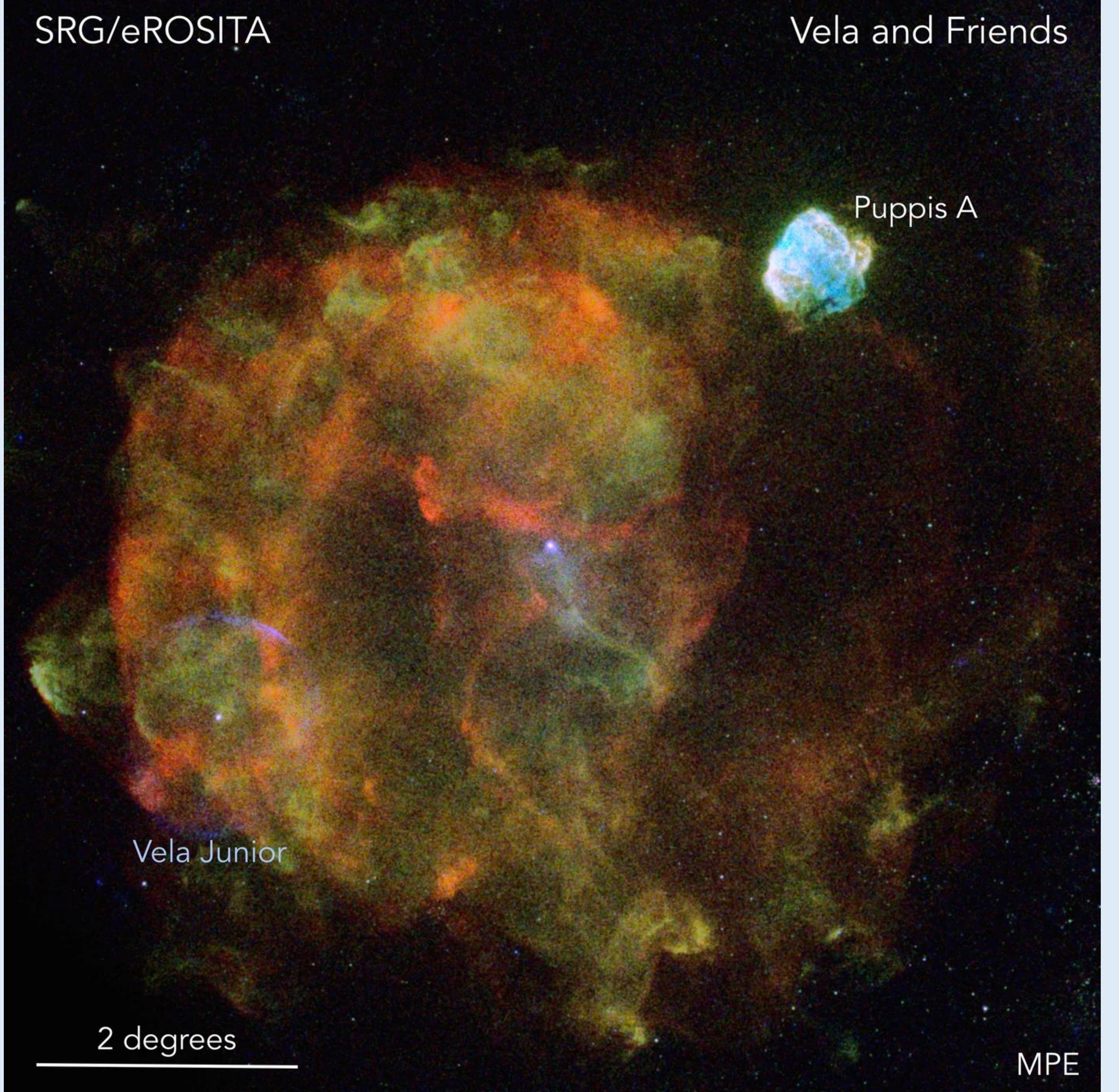
Merloni+ (2012)

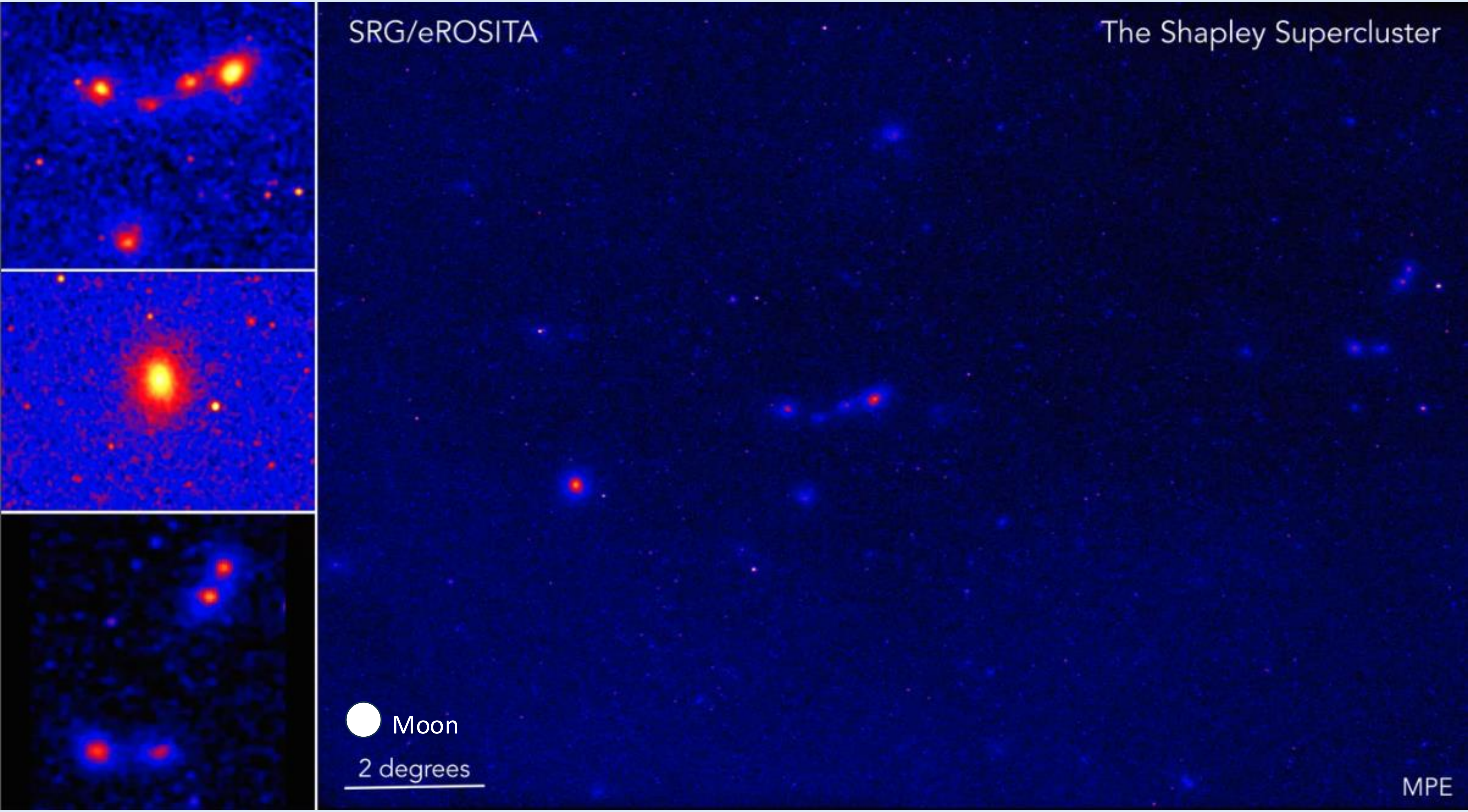
Navigating the eROSITA X-ray sky



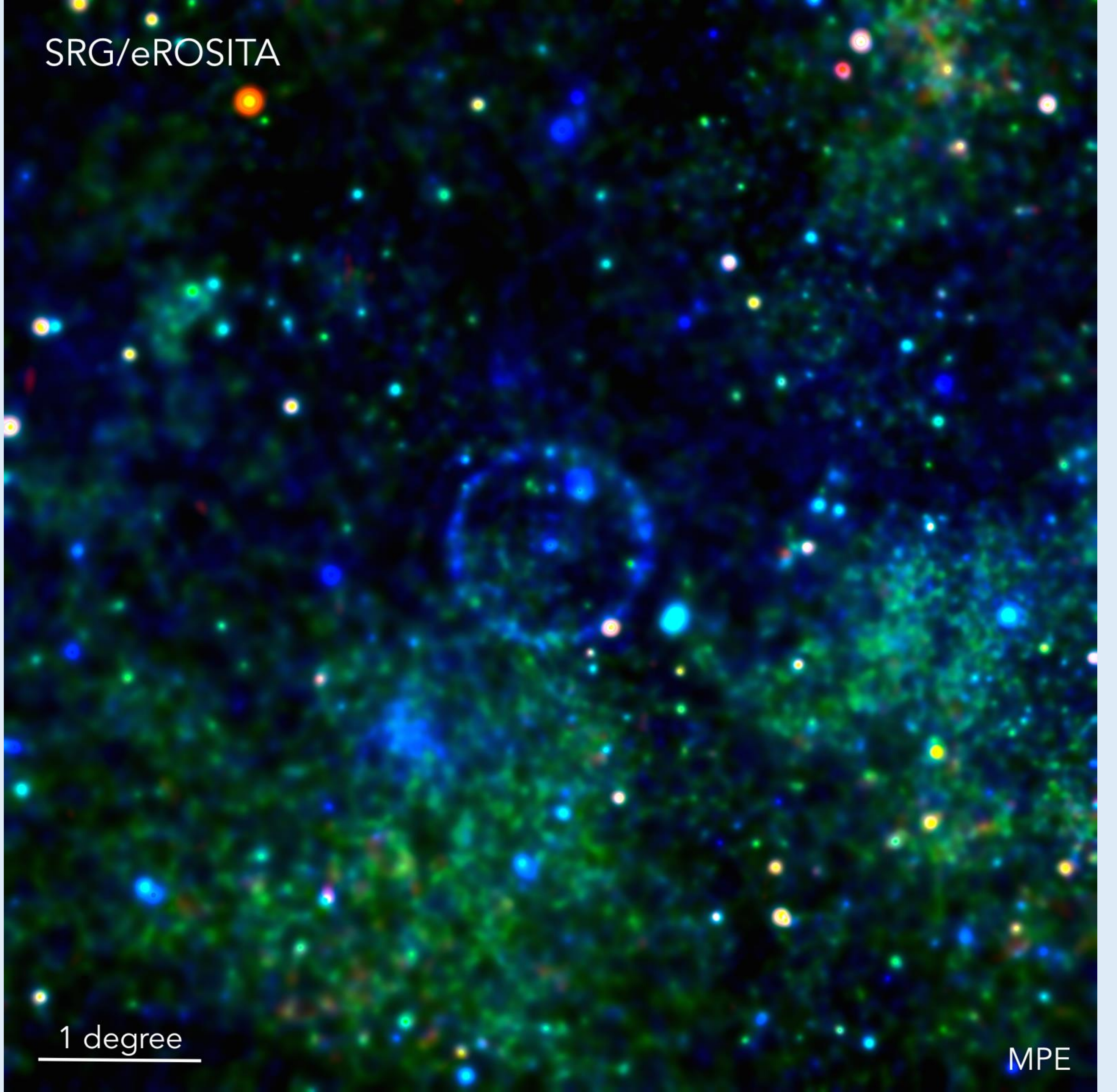

SRG/eROSITA
The Large Magellanic Cloud
LMC X-3
Foreground Star
SNR
SNRs
LMC X-4
SNRs
SNR
LMC X-1
LMC X-2
eROSITA First Light Image
3 degrees
MPE

- Exploded 12000 years ago
- 800 light-years away
- Vela Junior and Puppis A are more distant
- Remains of these found on Earth

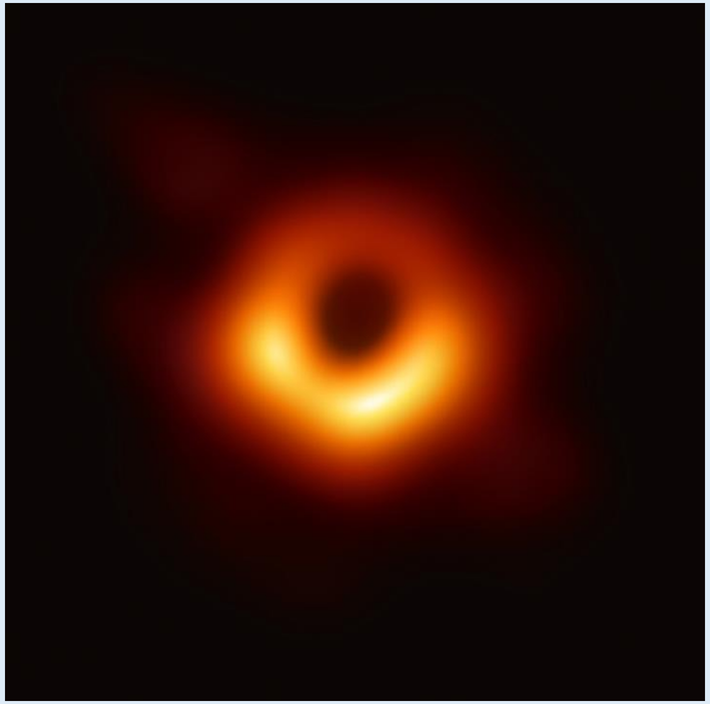



SRG/eROSITA
The Shapley Supercluster
Moon
2 degrees
MPE

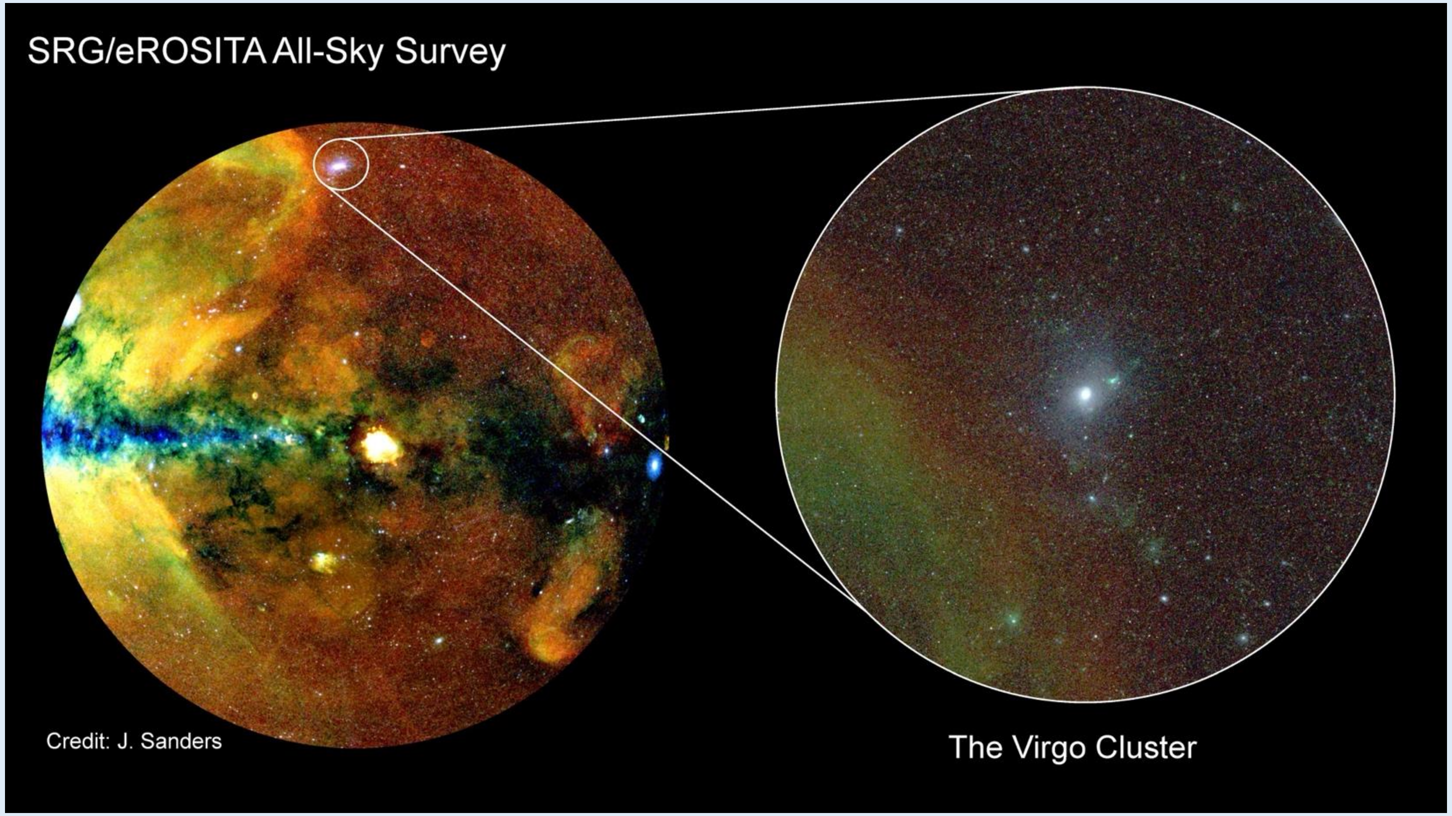
- 2019 Outburst (10000x brighter)
- 2020 echo from dust cloud in Milky way observed by eROSITA

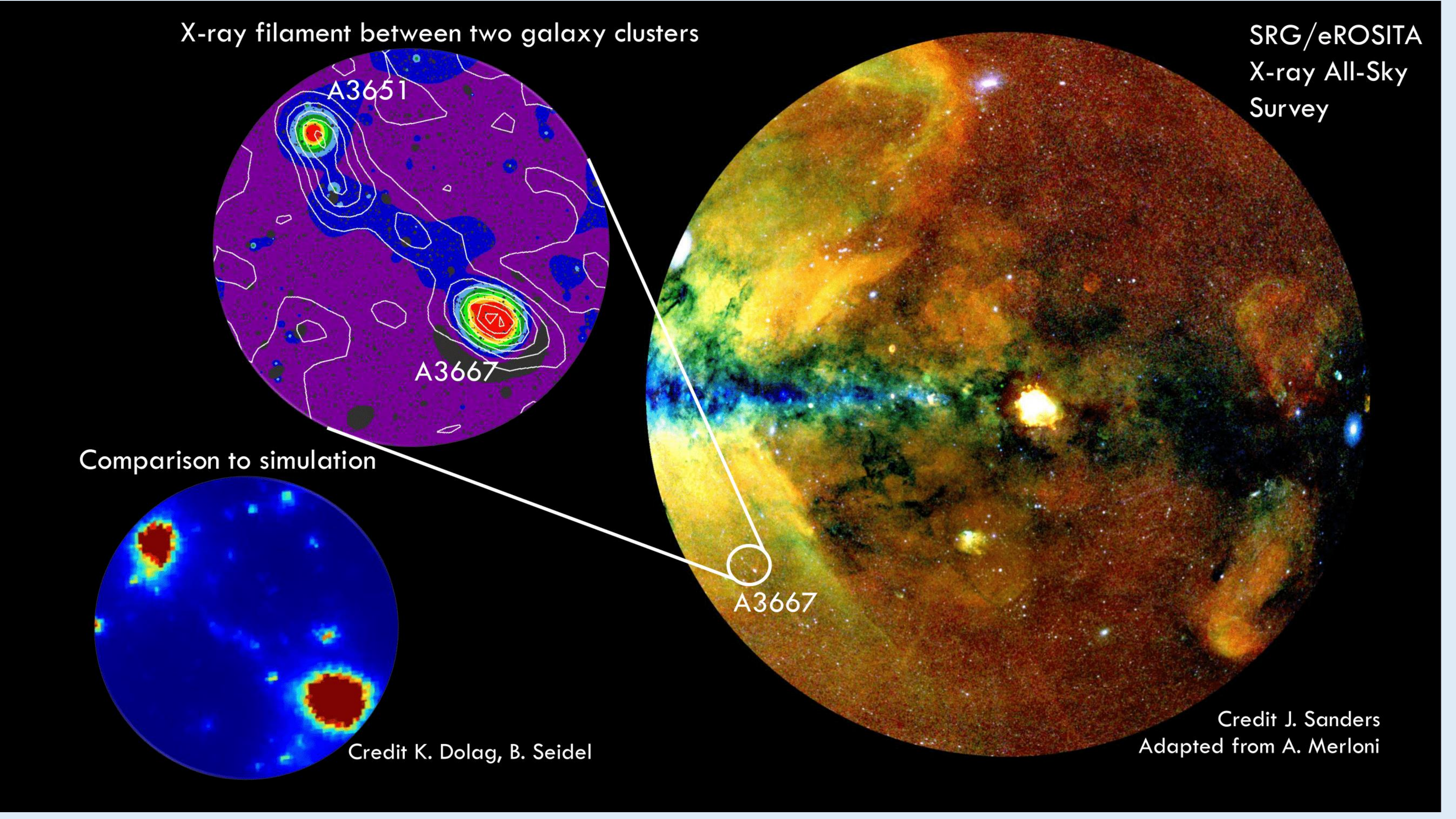


- Closest galaxy cluster
- M87 (known for picture of supermassive blackhole from the Event Horizon Telescope)



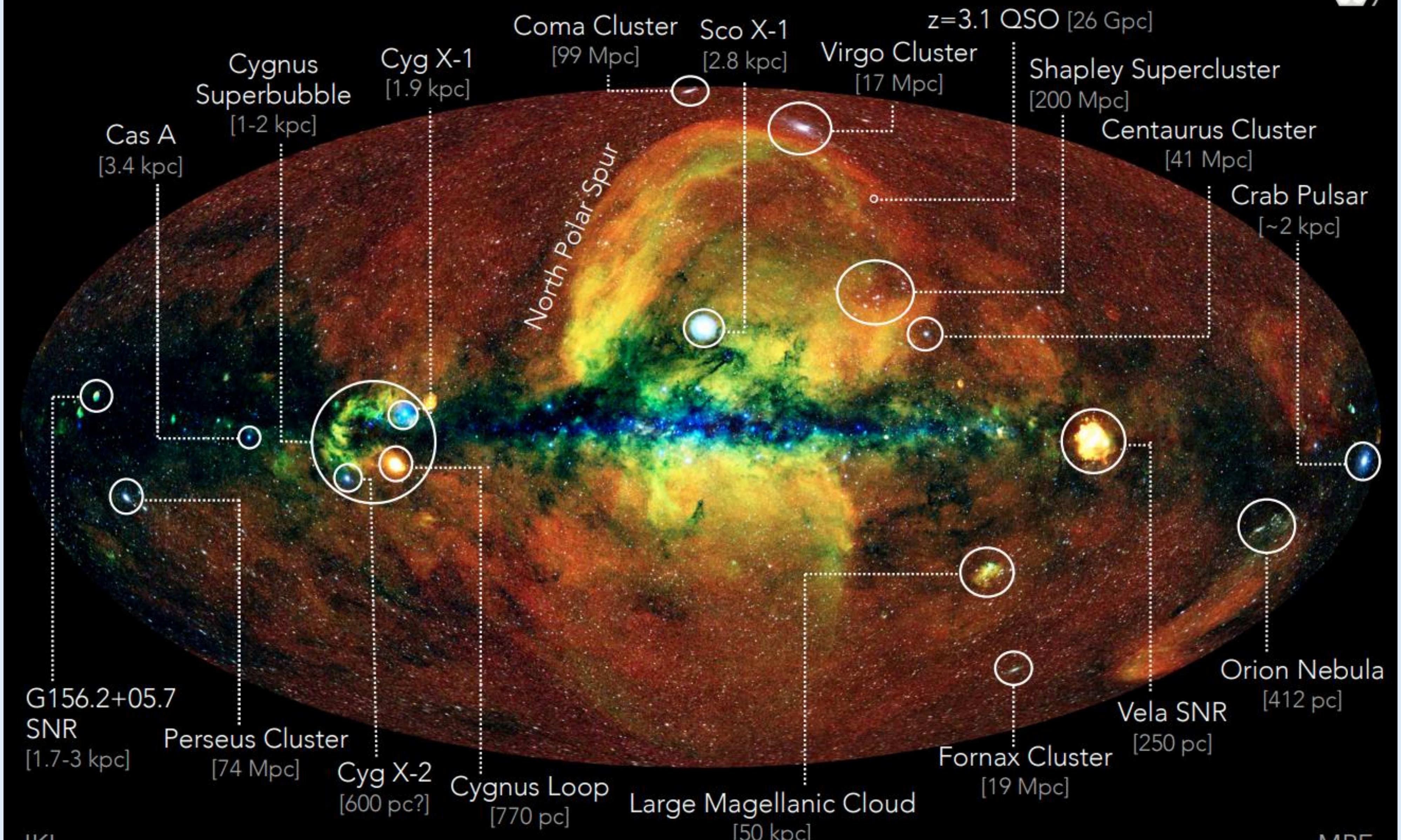
Credit: EHT Collaboration





X-ray filament between two galaxy clusters
A3651
A3667
Comparison to simulation
Credit K. Dolag, B. Seidel
SRG/eROSITA
X-ray All-Sky
Survey
A3667
Credit J. Sanders
Adapted from A. Merloni

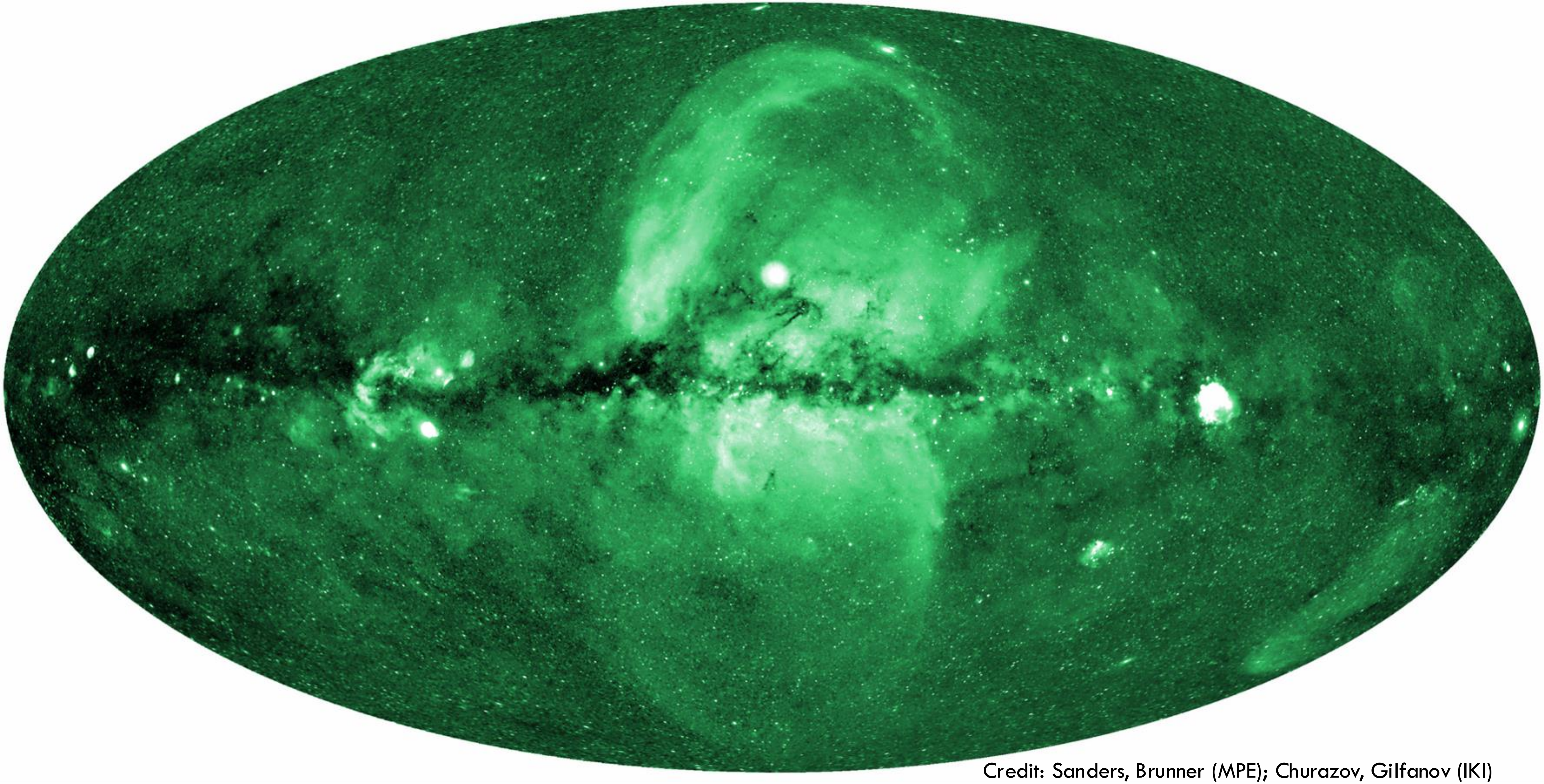
Navigating the eROSITA X-ray sky



IKI

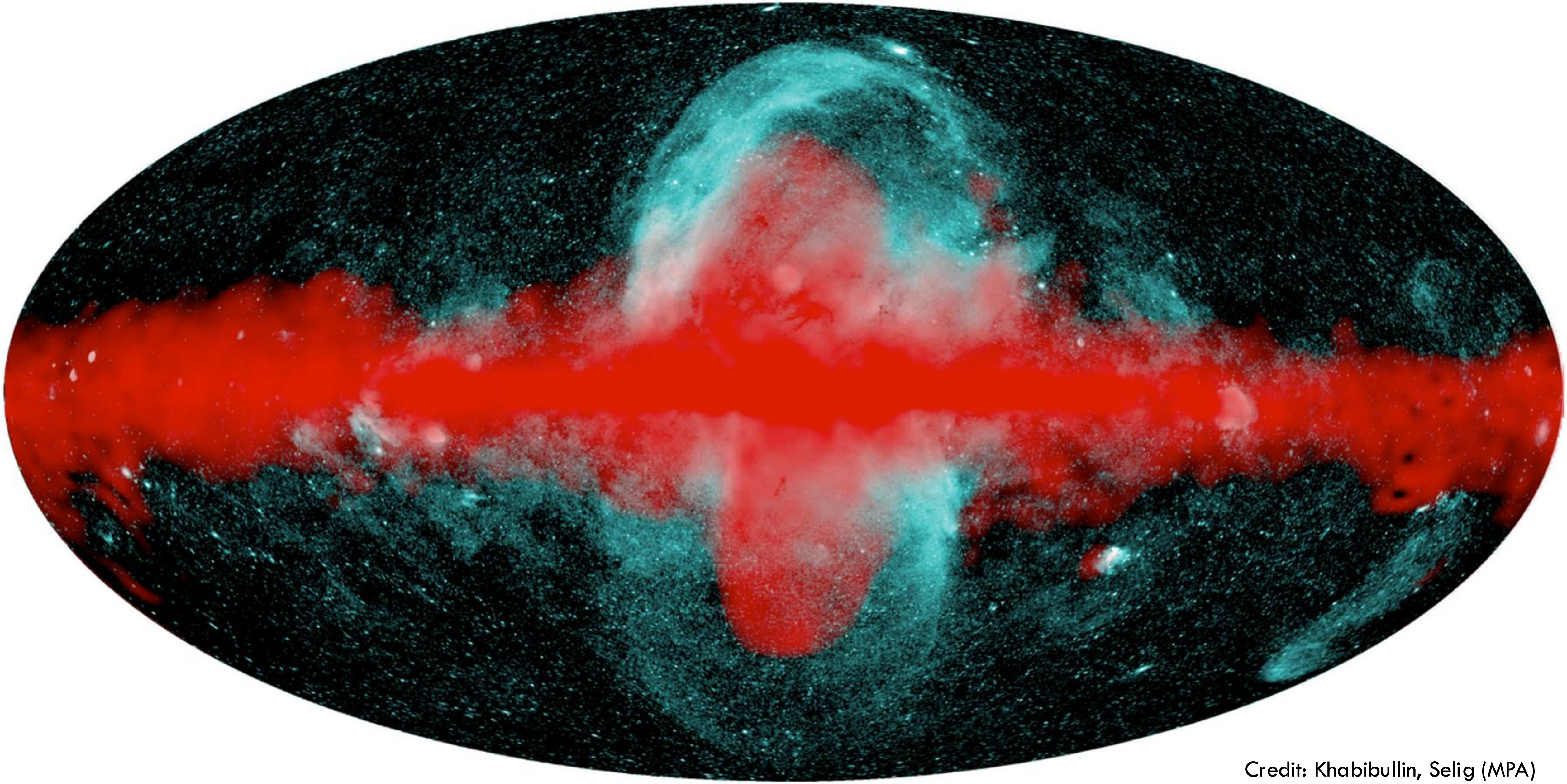
MPE

eRASS1, 0.6-1 keV

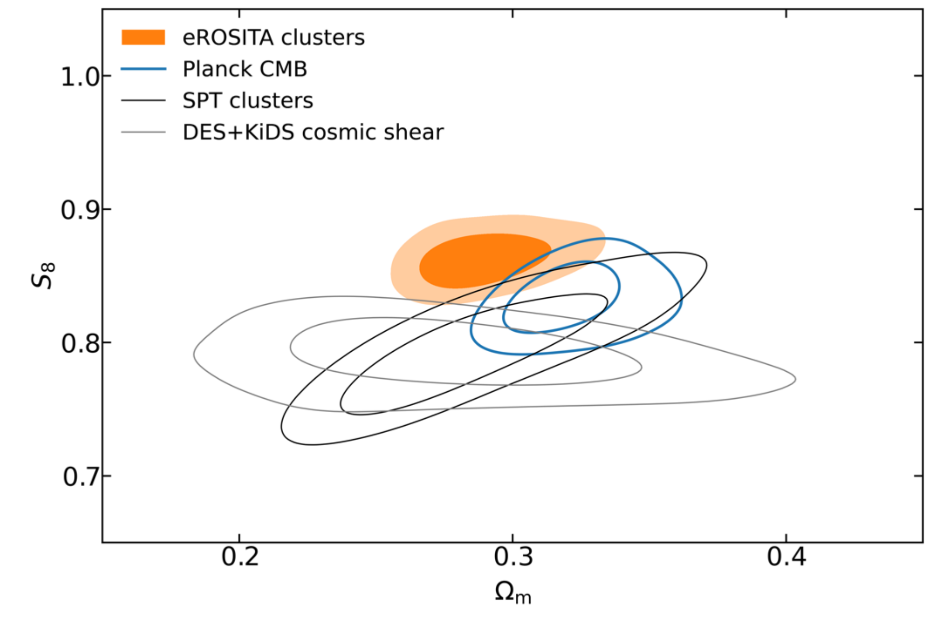


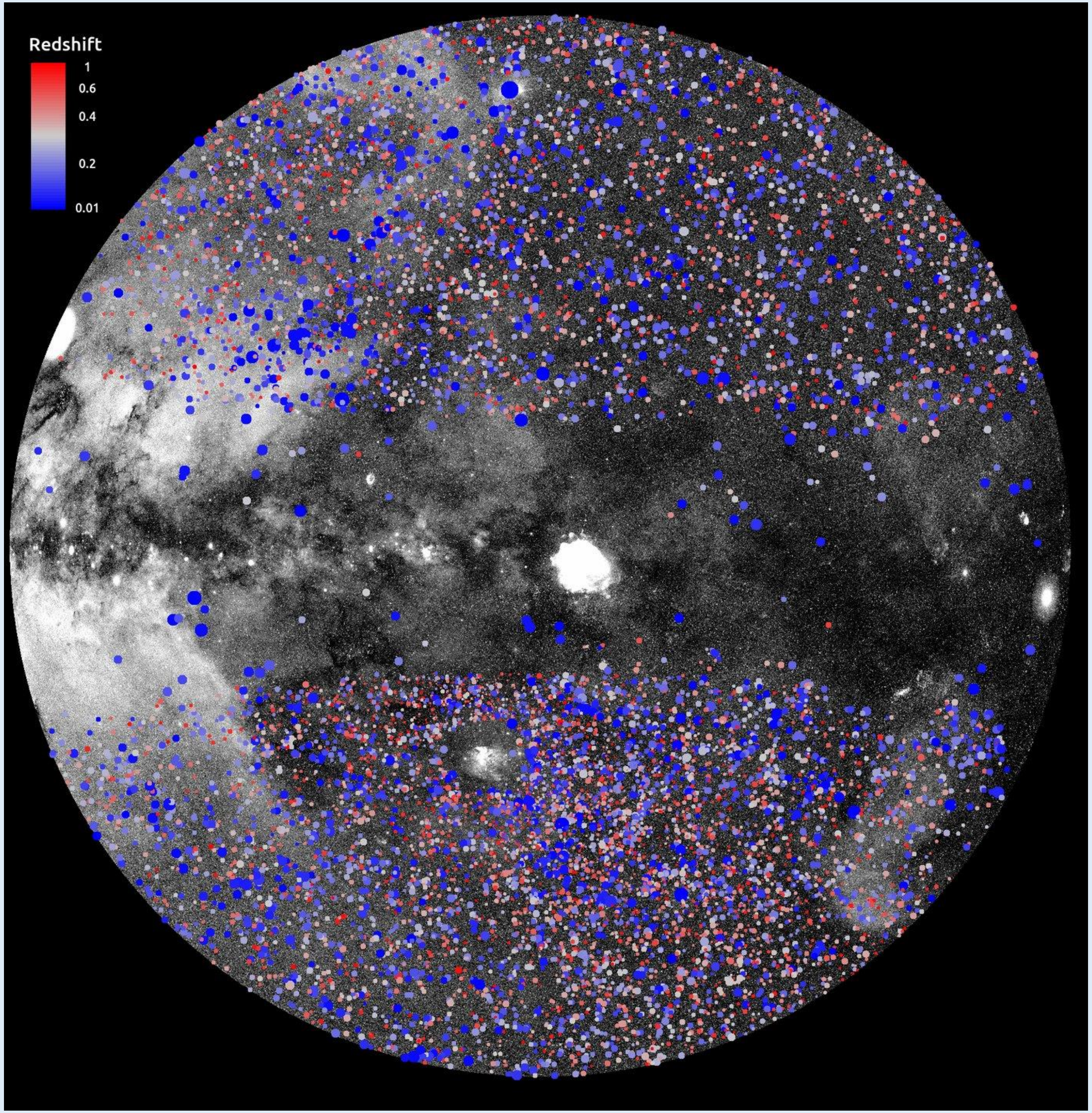
Credit: Sanders, Brunner (MPE); Churazov, Gilfanov (IKI)

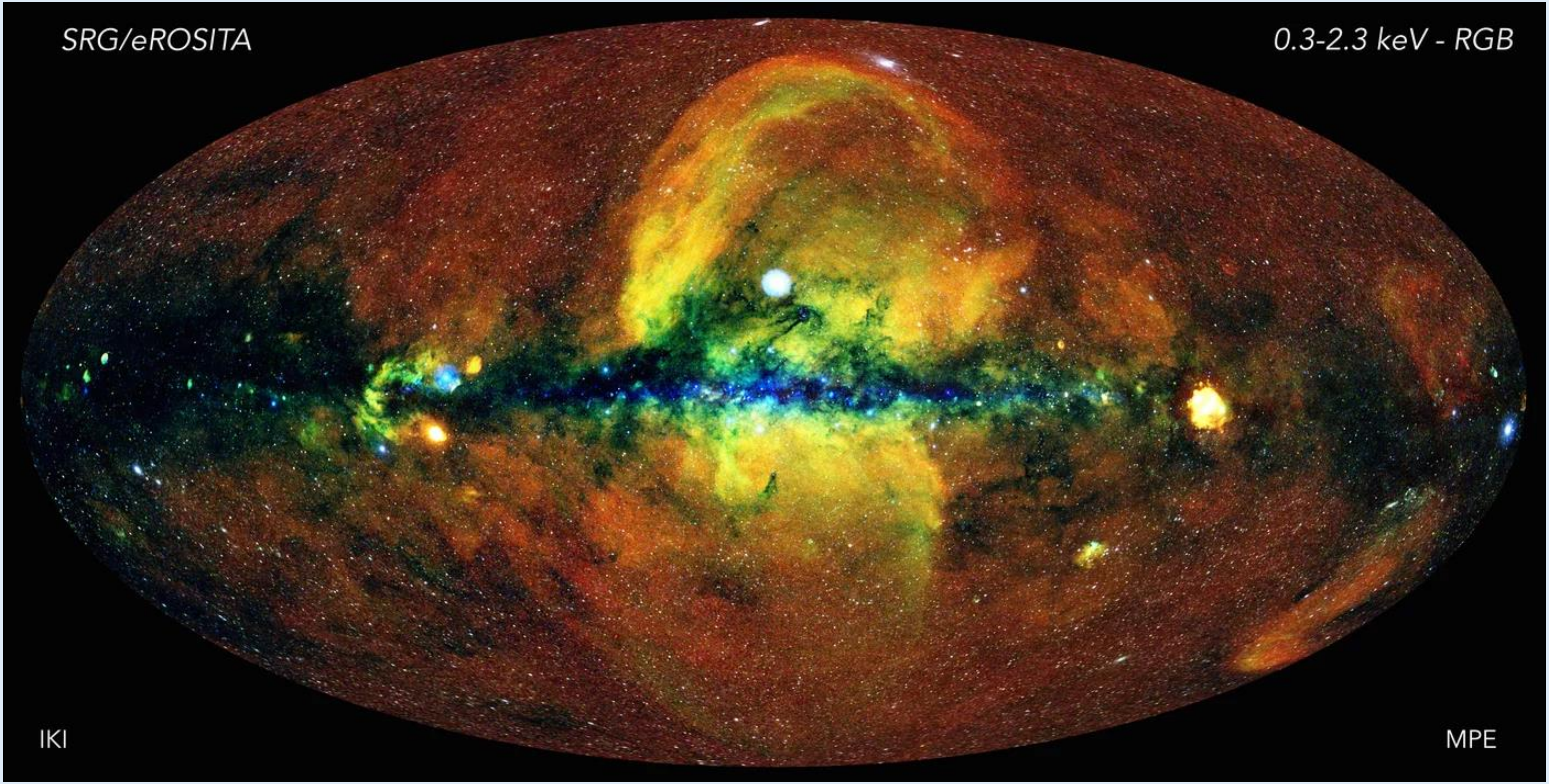
Fermi (>1GeV) vs. eRASS1, 0.6-1 keV



Credit: Khabibullin, Selig (MPA)

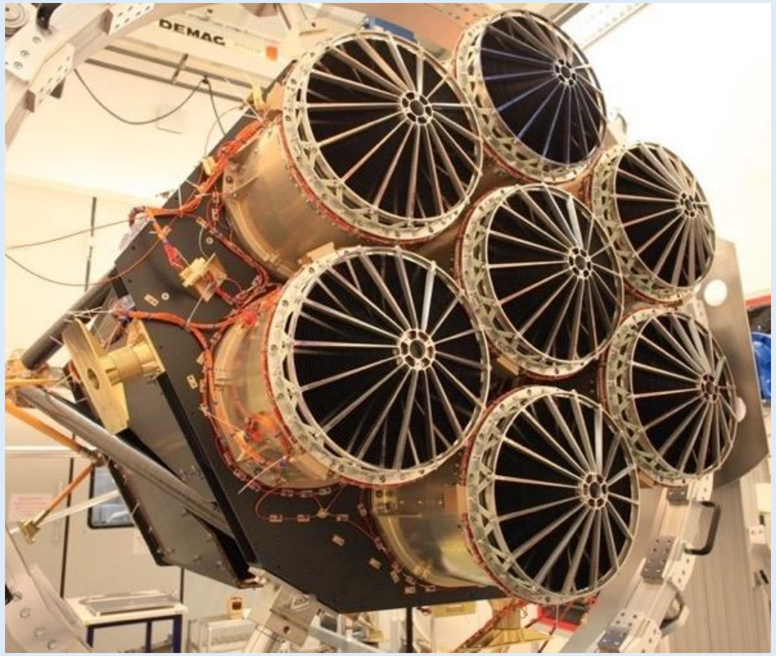

eROSITA clusters
Planck CMB
SPT clusters
DES+KiDS cosmic shear
1.0
0.9
0.8
0.7
S_8
0.2
0.3
0.4
Ω_m

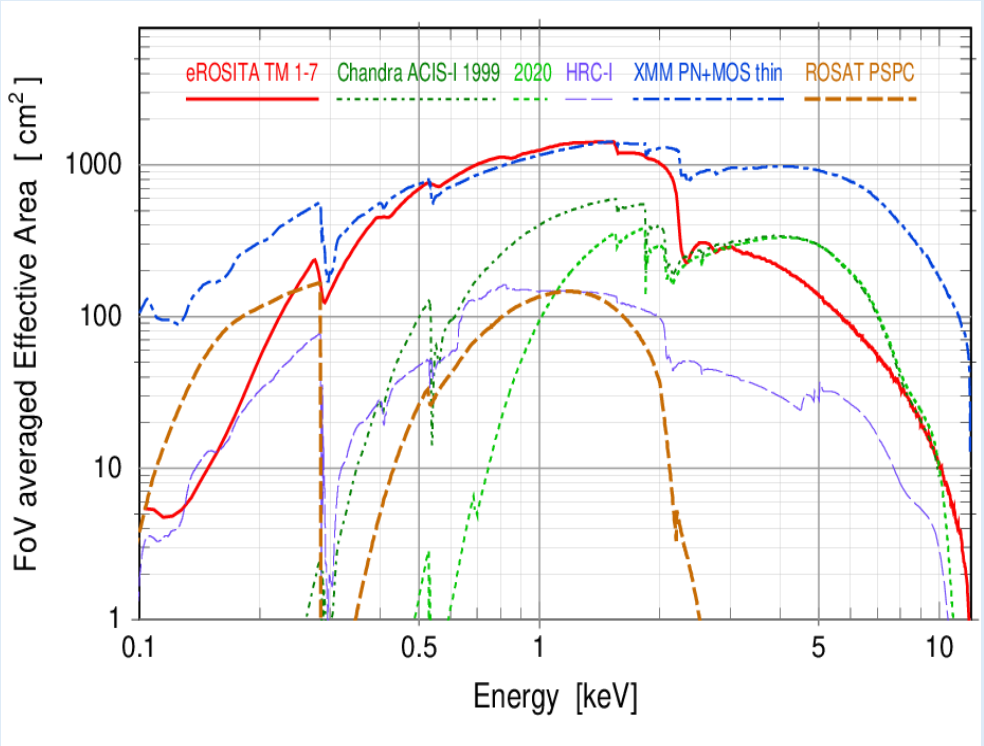

Redshift
1
0.6
0.4
0.2
0.01

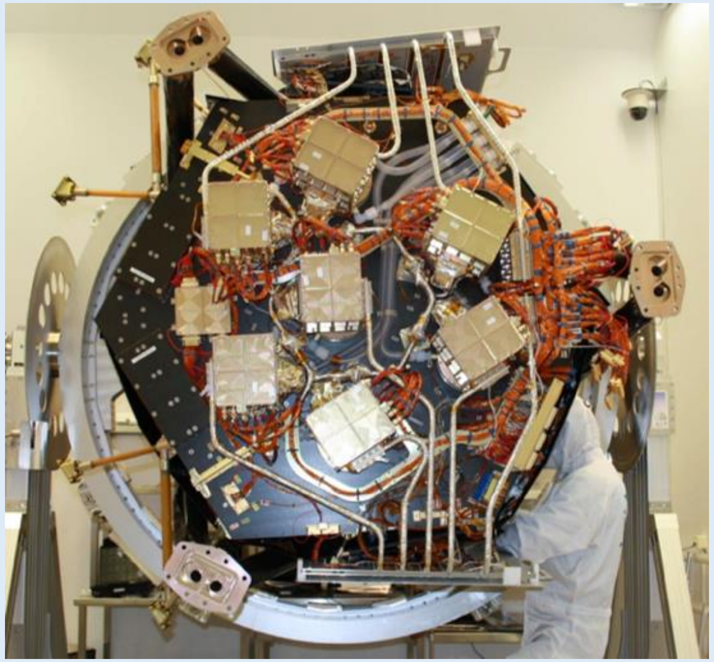

SRG/eROSITA
0.3-2.3 keV - RGB
IKI
MPE


Women in Science:
Celebrating Achievements in
Astronomy and STEM
a talk for International Women's Day
Thursday 6th March
1pm – 2pm
online/Mott LT
Dr Kimberly Arcand
Chandra X-ray Observatory
Center for Astrophysics
Harvard & Smithsonian
University of BRISTOL
School of Physics

eROSITA on SRG [Predehl+ 2021; Sunyaev+ 2021]

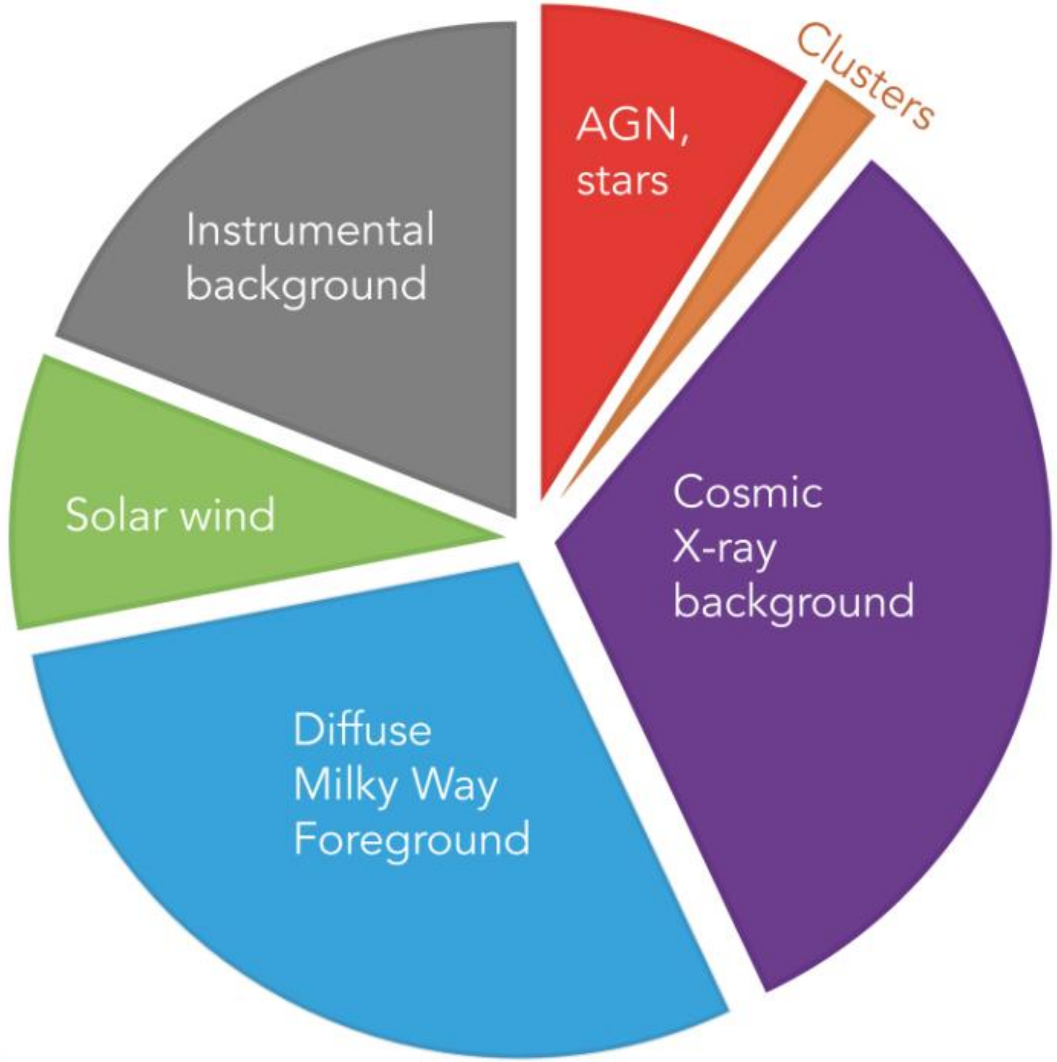






- Large Effective area (~**1300 cm^2 @1keV**)
- Large Field of view: 1 degree (diameter)
- Half-Energy width (HEW) ~18" (on-axis, point.); ~30" (FoV avg., survey)
  - Positional accuracy: ~4.5" (1σ)
- X-ray baffle: 92% stray light reduction
- pnCCD with framestore: 384x384x7~10^6 pixels (9.4"), no chip gaps, no 'out of time' events,
- **Spectral resolution** at all measured energies within specs (~80eV @1.5keV)

eRASS1: 170 Million calibrated photons (0.2-2 keV)



eROSITA

Merloni et al. (2024)

The eROSITA All-Sky Surveys by Numbers

- Completed 4 all-sky survey (12/2019 – 12/2021)
- Uniform exposure, avg.~800s; up to 120ks at the Ecliptic Poles (confusion limited)
- **~1.6 Billion** 0.2-5keV calibrated photons (~350 Gb telemetry)
- Typical (point-source) sensitivity:
  - Single pass (eRASS1,2,3,4)
    - ~5×10^{-14} erg/s/cm^2 [0.2-2.3 keV]; **4-5x deeper than RASS**
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