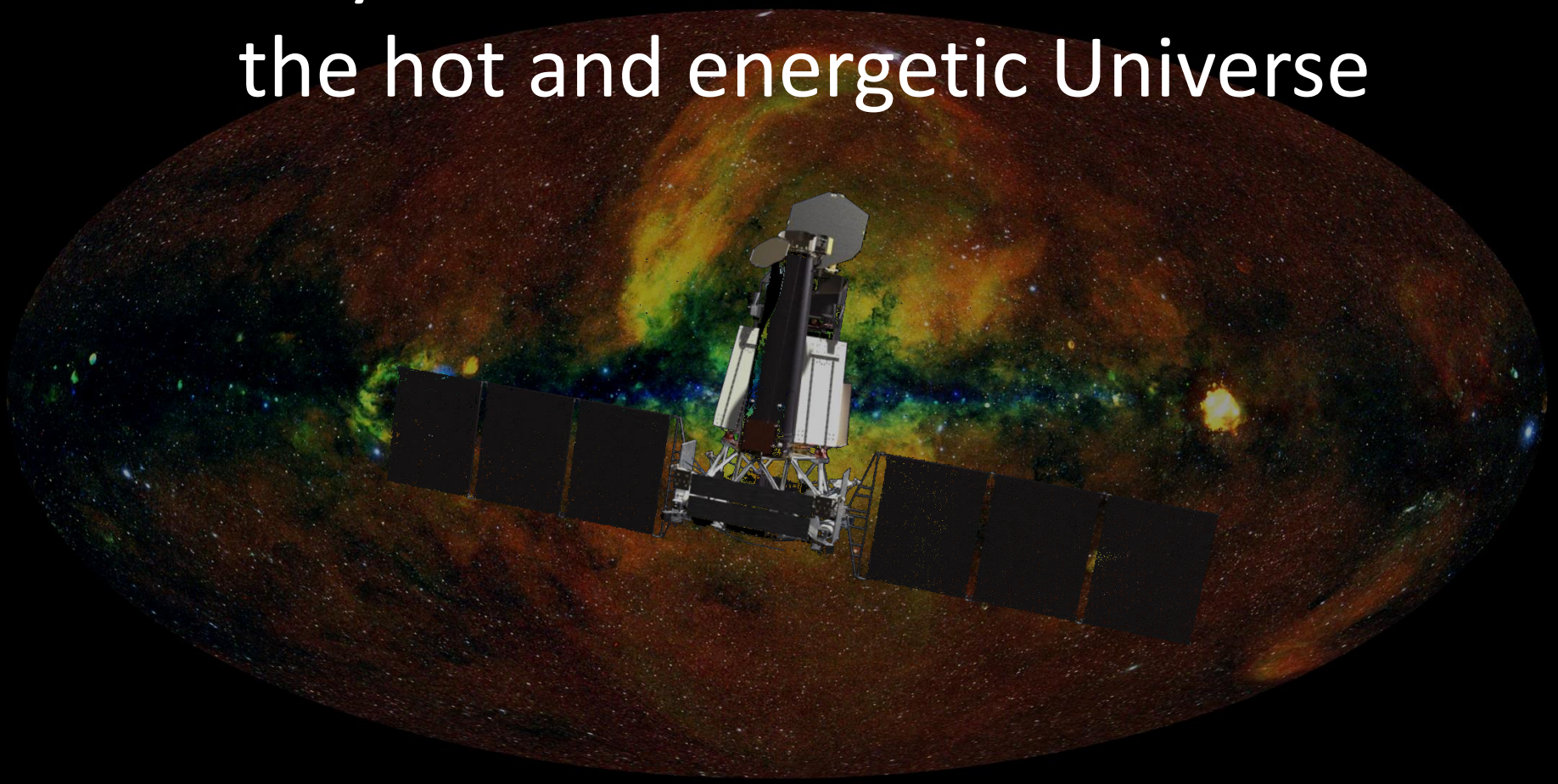
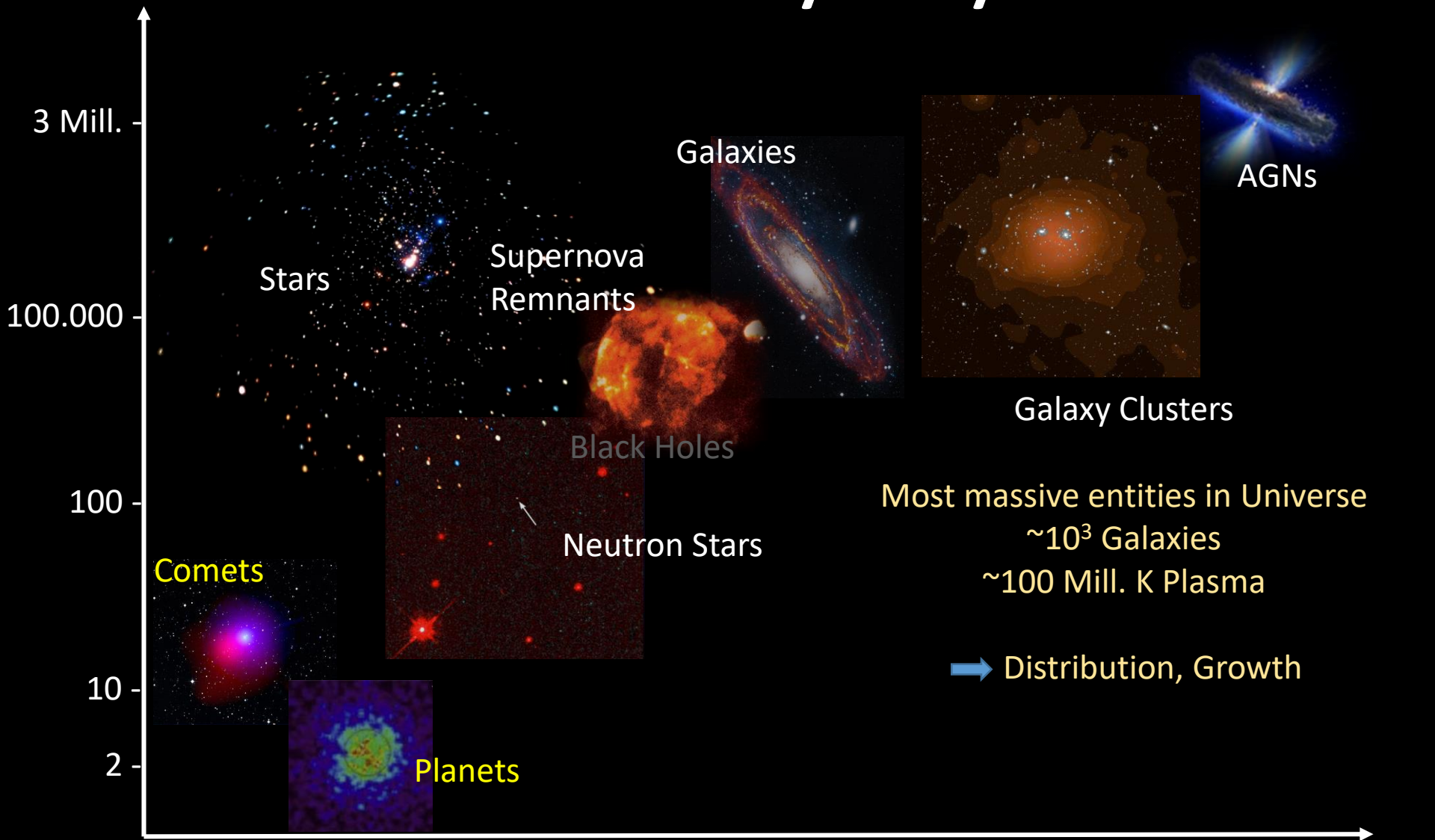
# X-ray Instrumentation to observe the hot and energetic Universe



Peter Predehl (MPE)

High Precision X-ray Measurements 2021

# The X-ray Sky



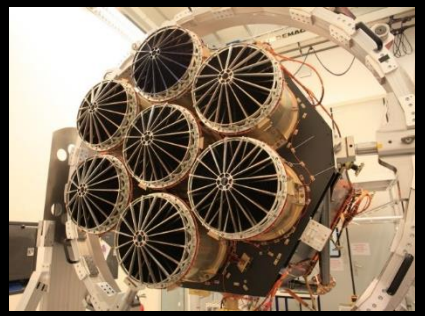

Most massive entities in Universe
~$10^3$ Galaxies
~100 Mill. K Plasma

➡ Distribution, Growth

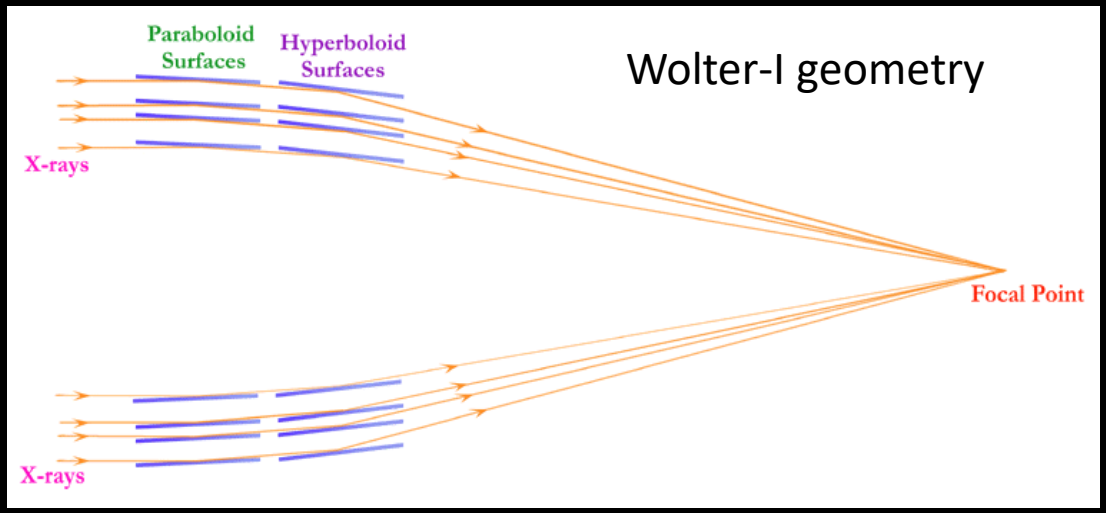
# Some (trivial) constraints


- only outside of earth‘s atmosphere
  - mechanical load during launch
    vibration, acoustic noise
  - thermal load in orbit
    cold but cooling by radiation only
    - difficult in low earth orbit
  - radiation load (cosmic rays)
    - SEUs in electronics, bkgr in detectors
  - no way to repair → redundancy
  - limited data rate
  - vacuum in space is stable ☺

- instrument+spacecraft need to fit into fairing



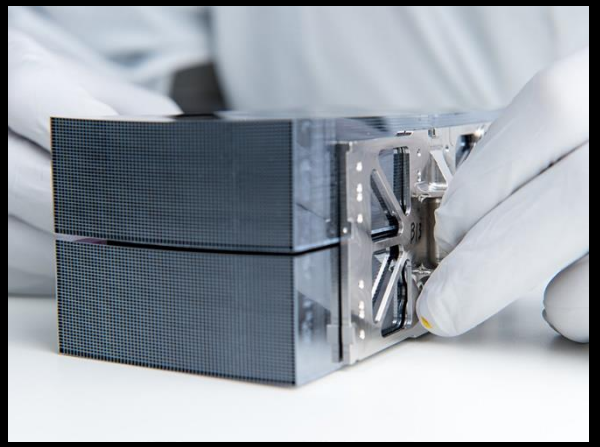
# Imaging: Optics




## Others

- double cone approximation
- Wolter-II (Soho)
- Kirkpatrick-Baez

- Lenses, Fresnel-lenses?

Polished Zerodur
ROSAT (D) 3“
Chandra (NASA) 0.5“
eff area < 1000cm²

Nickel e-forming
XMM (ESA) 15 arcsec
eROSITA (D) 16 arcsec
eff. area > 1000cm²

Silicon Pore Optics

Athena (ESA) 5“ (goal)
eff. area > 1m²

# Imaging: Detectors

*(but also non-imaging: SDDs, e.g. on NICER)*

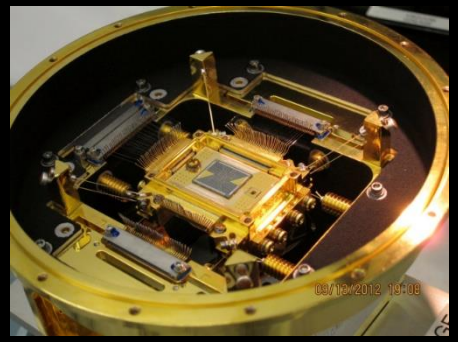
- Past:
- Proportional Counters — 250µm, E/ΔE ~ 0.4keV @ 1keV, fast, bkgr suppression
- Channelplate Counters — 25µm, E/ΔE ~ 1, fast, bkgr suppression

- Current:
- Si detectors, CCDs — ΔE ~60eV-140eV, >90% QE, slow, no bkgr suppr. cooling required (-90°C)
- Cd(Zn)Te detectors — for higher energies *(NuStar, ART-XC)*

- Future (current failed): — microcalorimeters, ΔE ~2eV, <100mK

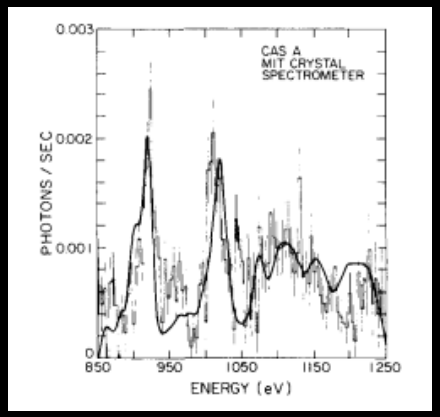
PSPC
ROSAT, 1990

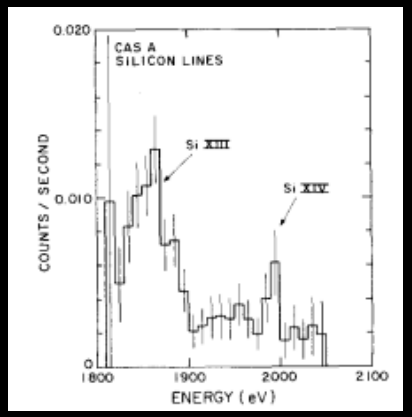

MOS CCD
XMM-Newton, 1999



SXS
Hitomi, 2016

# Dispersive Spectroscopy

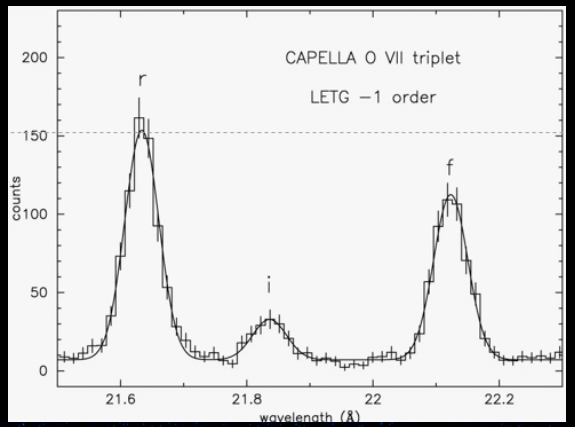


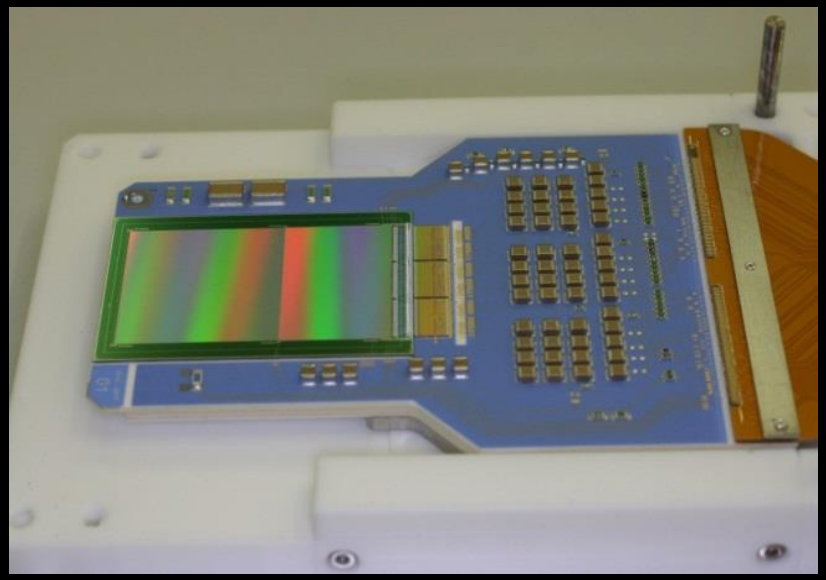

Bragg Crystal Spectrometer
on HEAO-B (NASA, 1978)

LETG on Chandra (1999)

540 grating elements
1008l/mm, freestanding
$\lambda/\Delta\lambda < 1000$

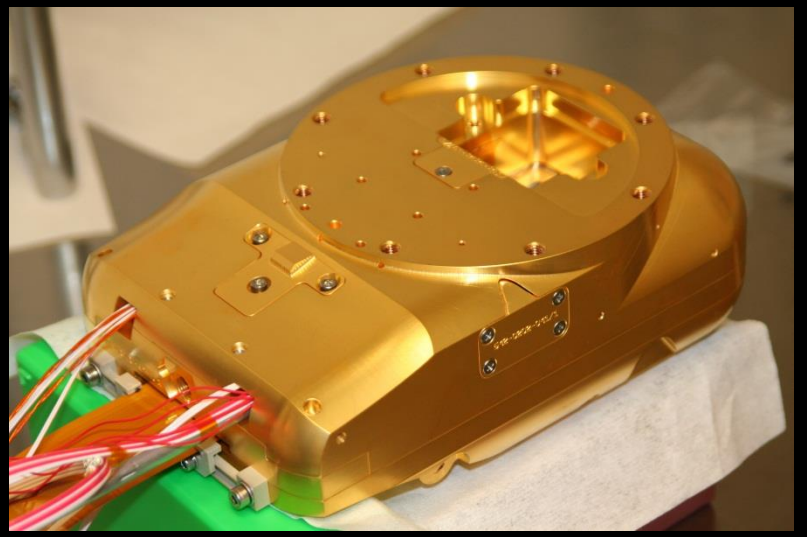


# eROSITA Camera(s)



pnCCD, frame store area

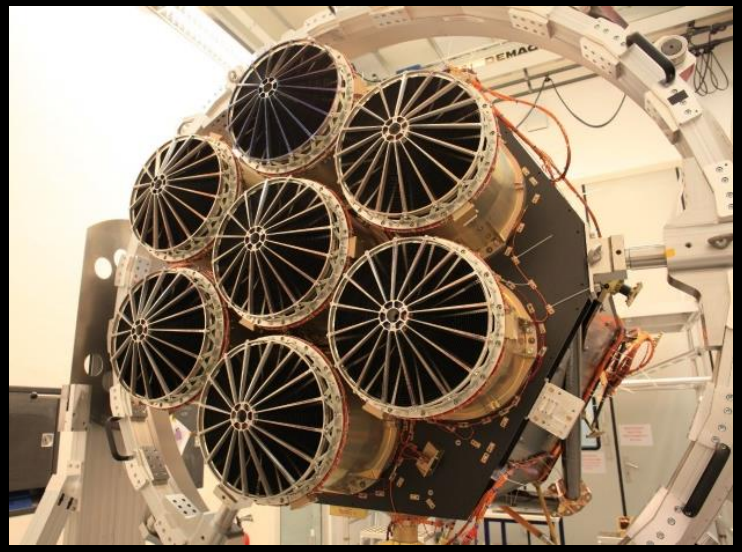
384 × 384 pixels, 75µm (9“)
50 msec resolution
op. Temp. -86°C
<140eV @ 5.9keV (Mn Kα)

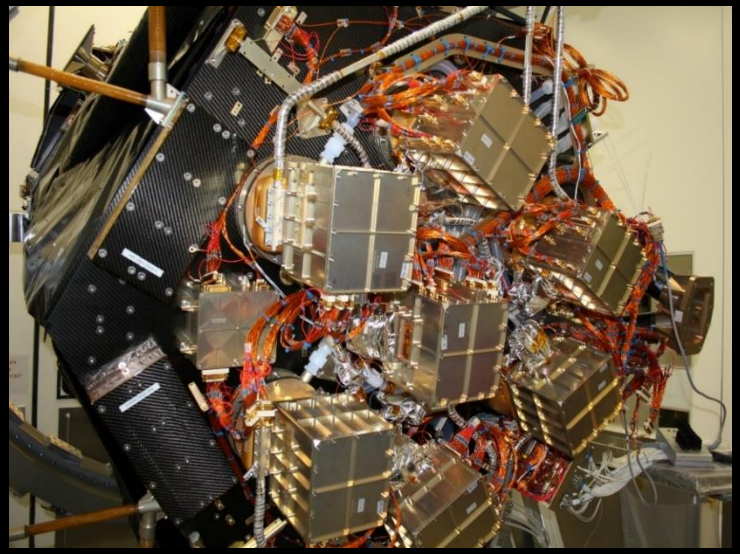


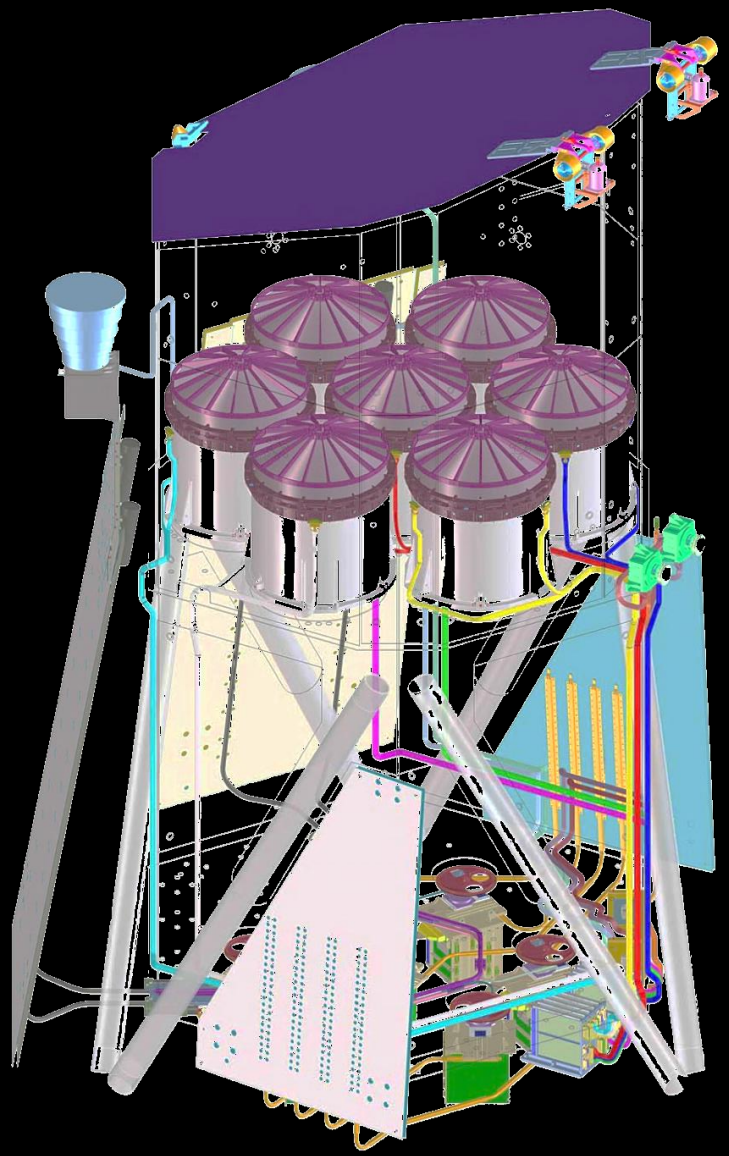
Massive copper shielding against CR damages

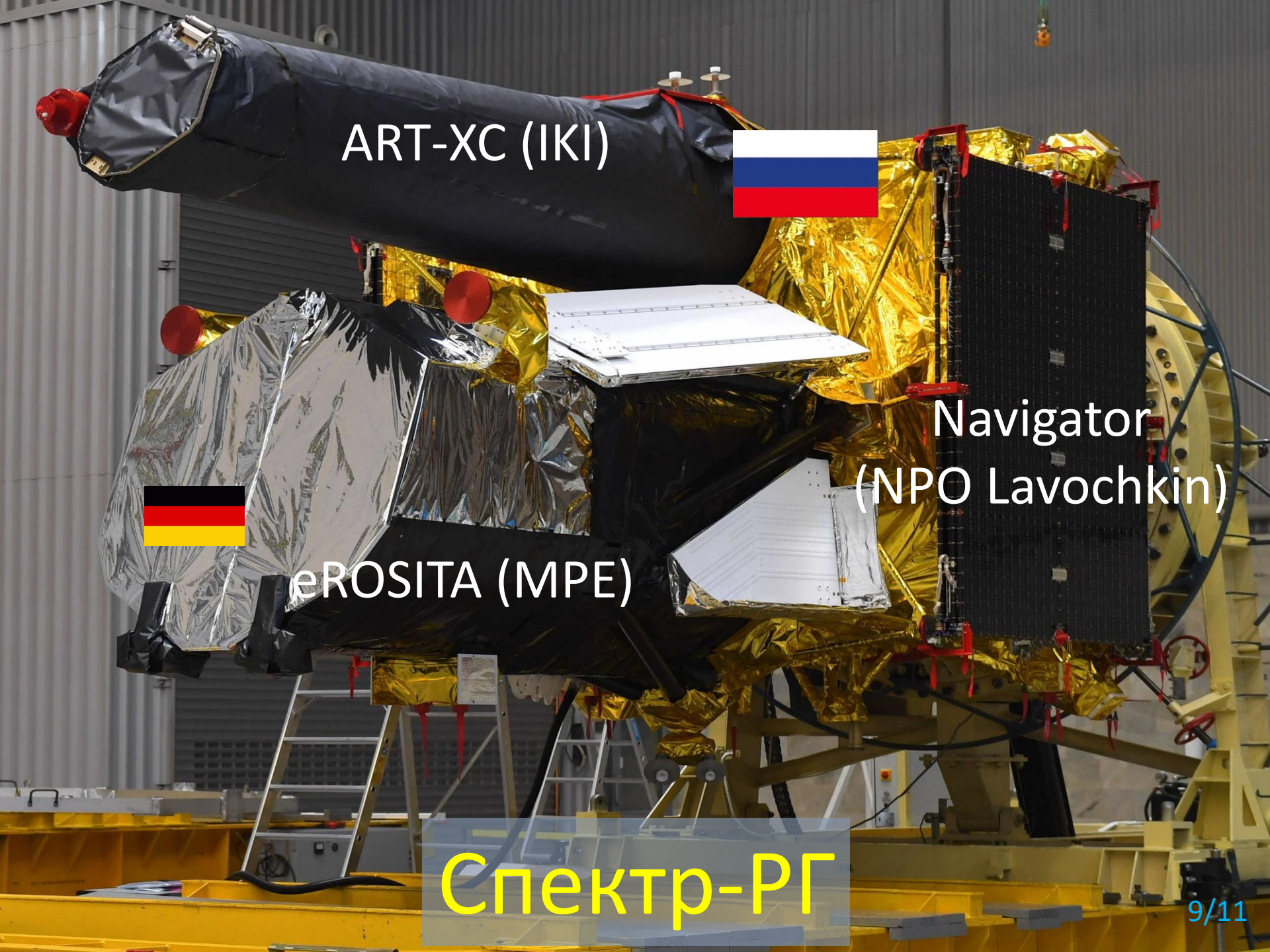
Graded shield (Al, Be) inside against fluorescence

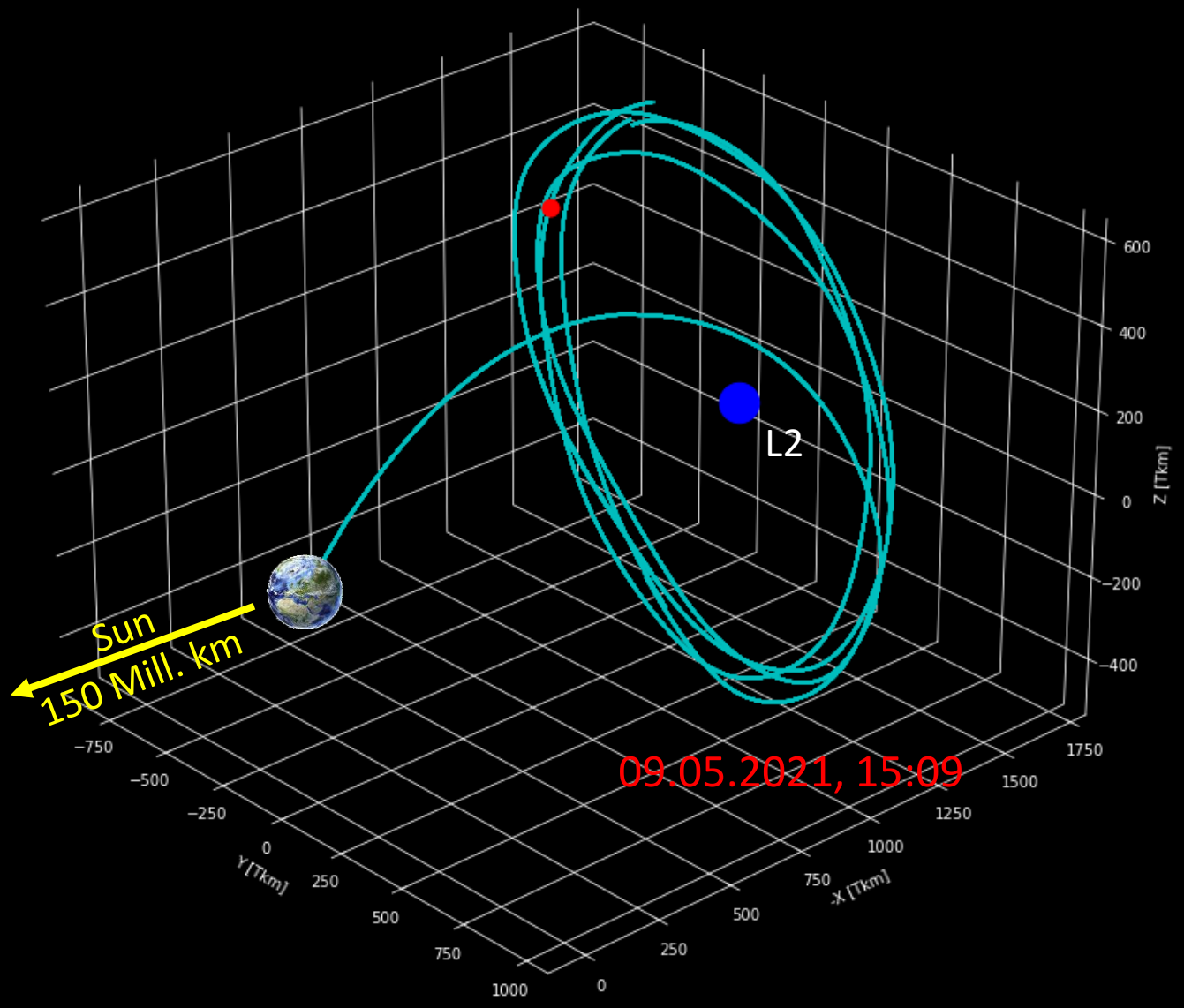
# eROSITA Telescope





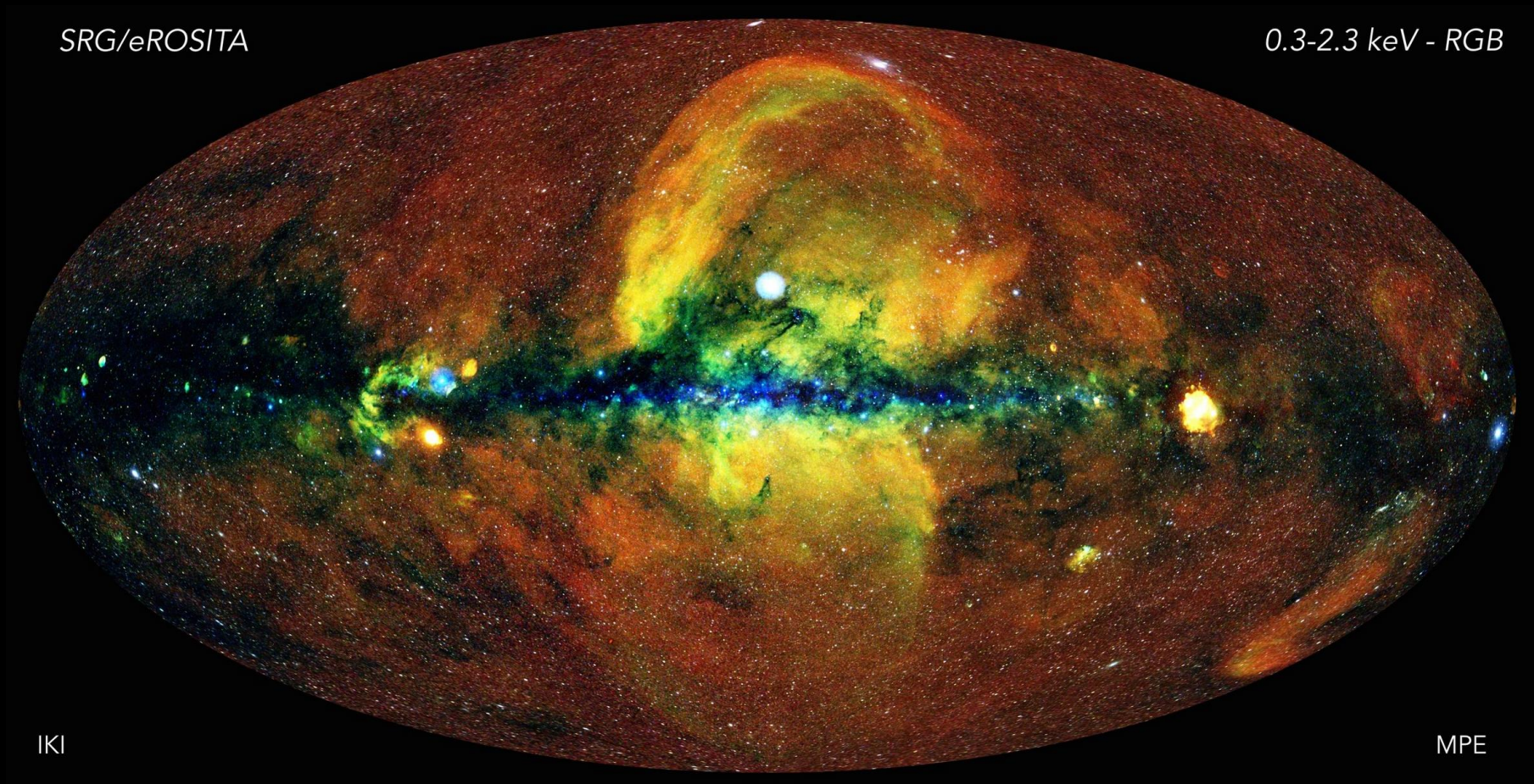



ART-XC (IKI)
Navigator
(NPO Lavochkin)
eROSITA (MPE)
Спектр-РГ




- **4 years**: 8 all sky surveys (6 rotations/day)

# eRASS1 (1/8)



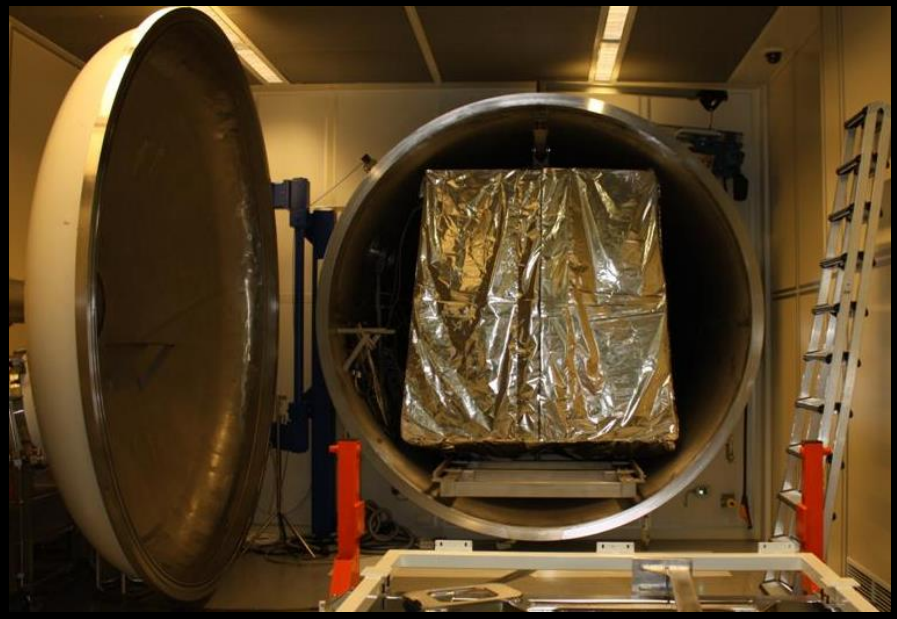

> 1.000.000 X-ray sources found

More than all X-ray observatories of the last 50 years

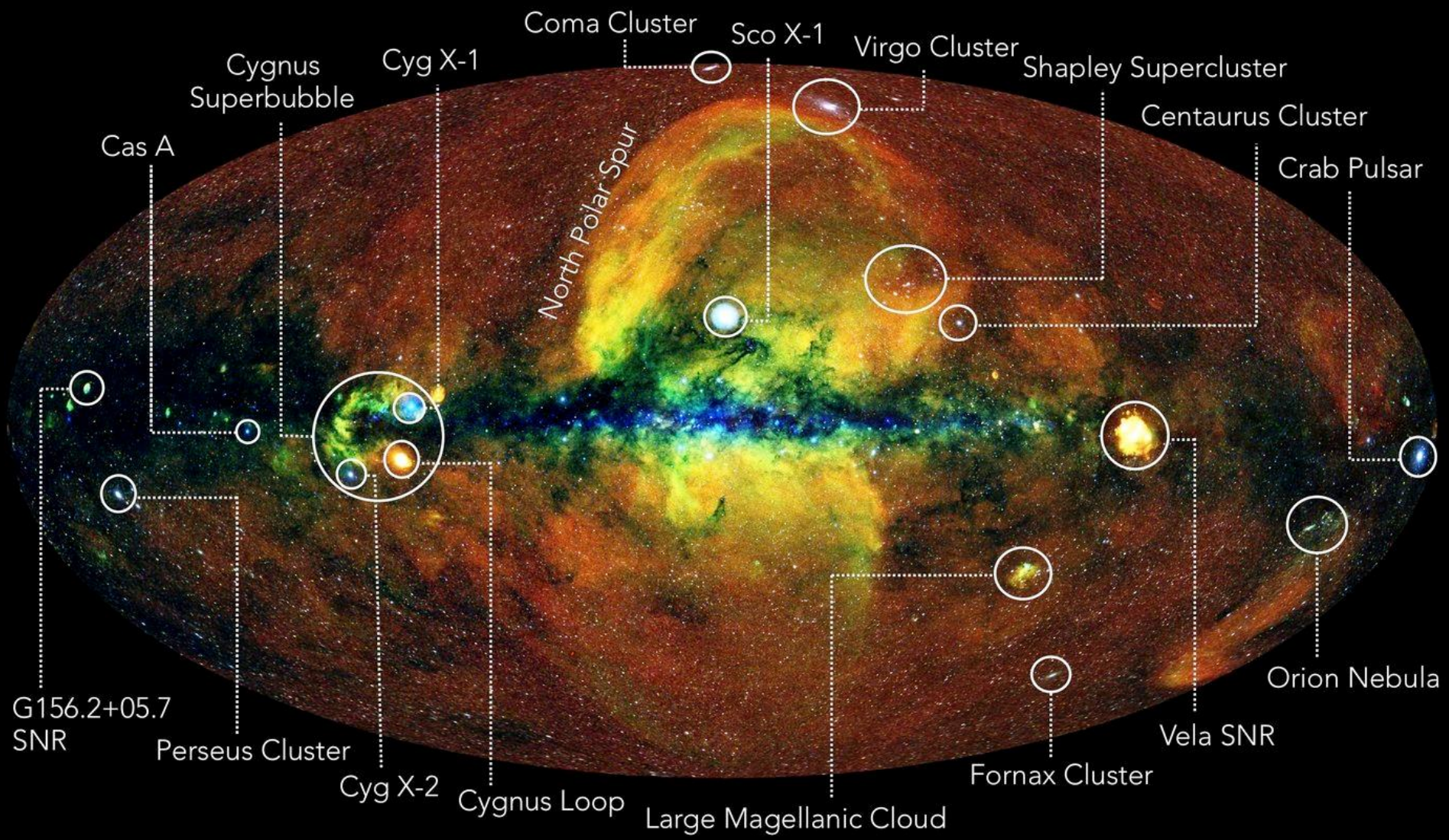
*Predehl, Sunyaev, et al., 2020*


*Photo: V. Burwitz (MPE)*

# PUMA & PANTER



# Navigating the eROSITA X-ray sky




IKI

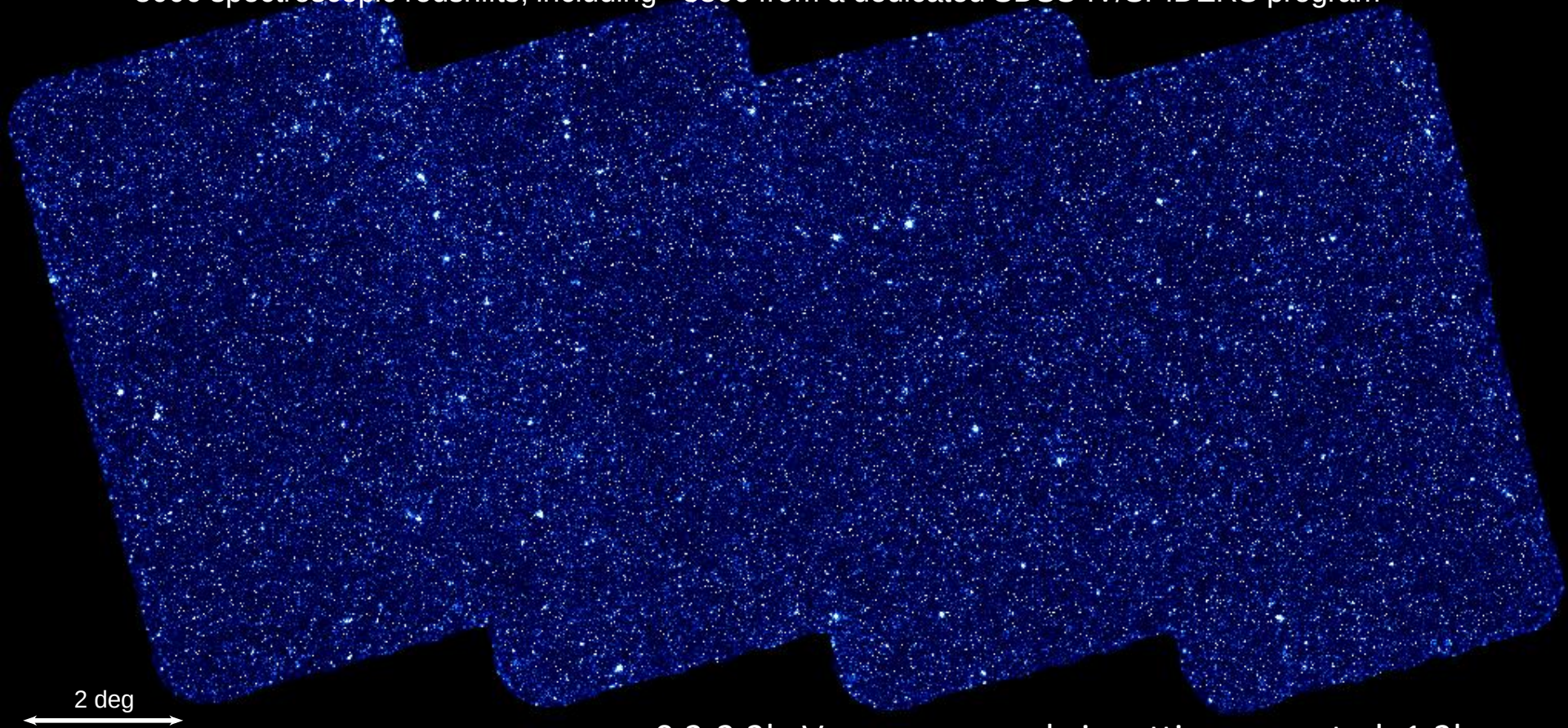
SRG/eROSITA 0.3-2.3 keV - RGB Map

MPE

# eFEDS AGN

## More than 25k point-sources detected

- ~8000 spectroscopic redshifts, including ~3800 from a dedicated SDSS-IV/SPIDERS program

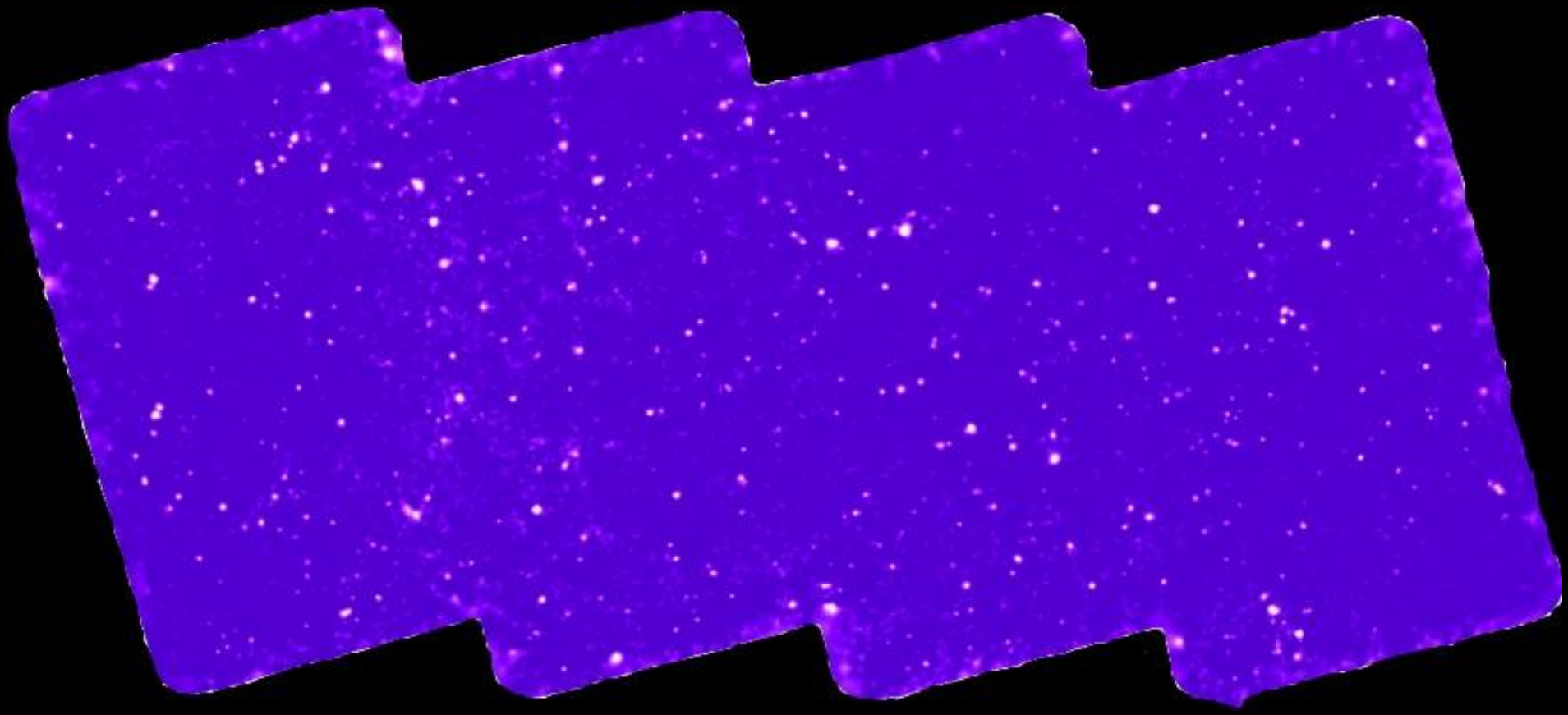



0.2-2.3keV, exposure and vignetting corrected, 1.2ksec

*Brunner et al., 2021*

# eFEDS Clusters

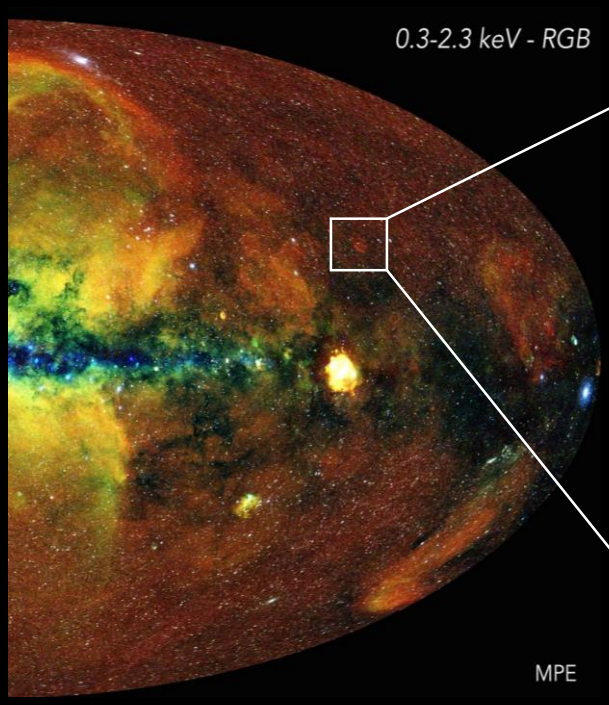
542 galaxy clusters detected by eROSITA
~ 440 already optically confirmed 0.1<z<1.3

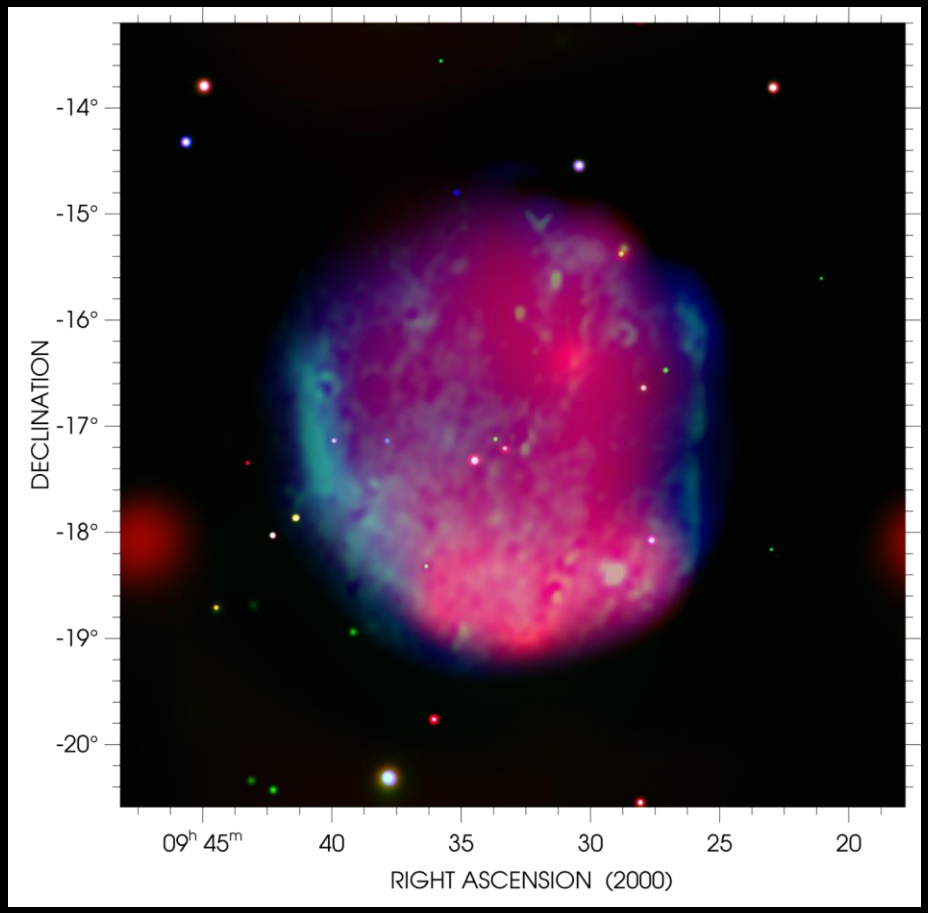


0.2-2.3keV, exposure and vignetting corrected, 1.2ksec

*Liu et al., 2021, Klein et al., 2021*

# Hoinga – the largest supernova remnant ever discovered with X-rays




*Becker et al., 2021*

SNR: 4.4° Ø, d~500pc, 17 - 30.000 yrs