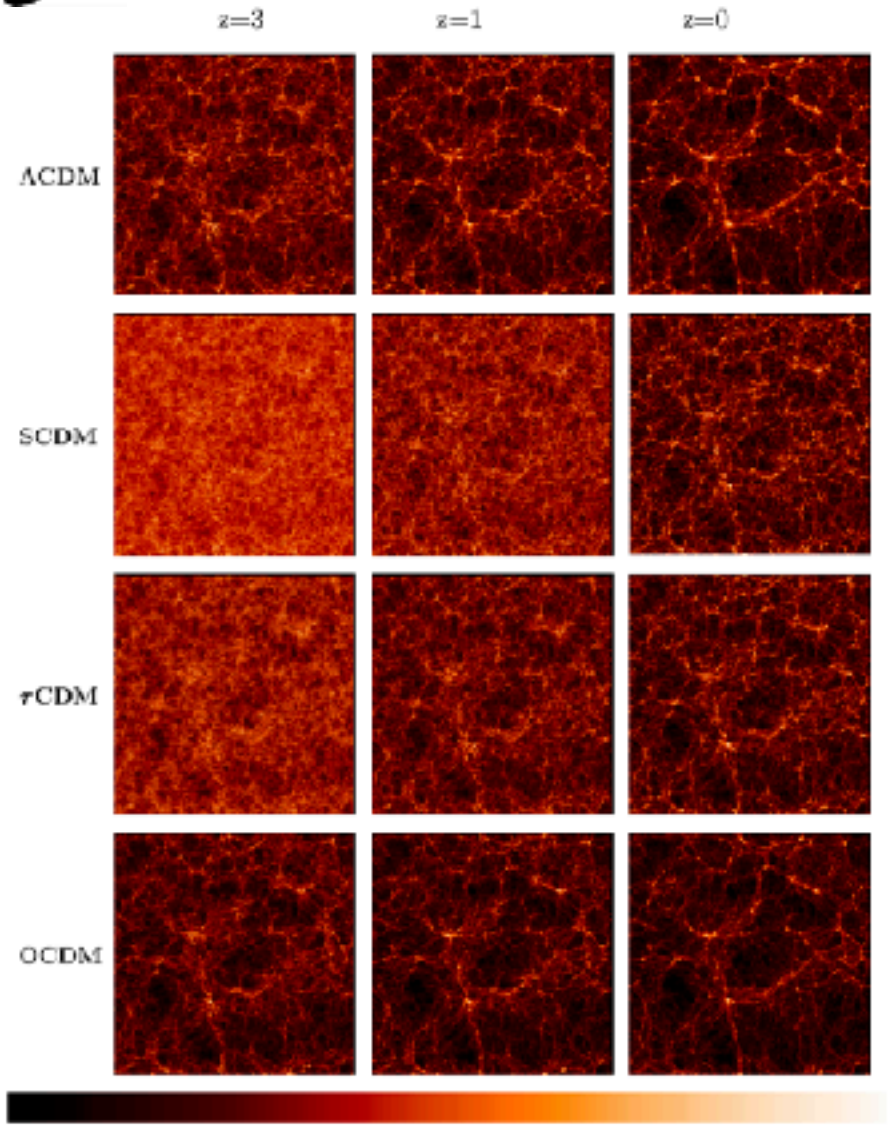
New eyes on the X-ray sky: First Results from eROSITA on SRG

Andrea Merloni (MPE)
@andmerloni

Outline

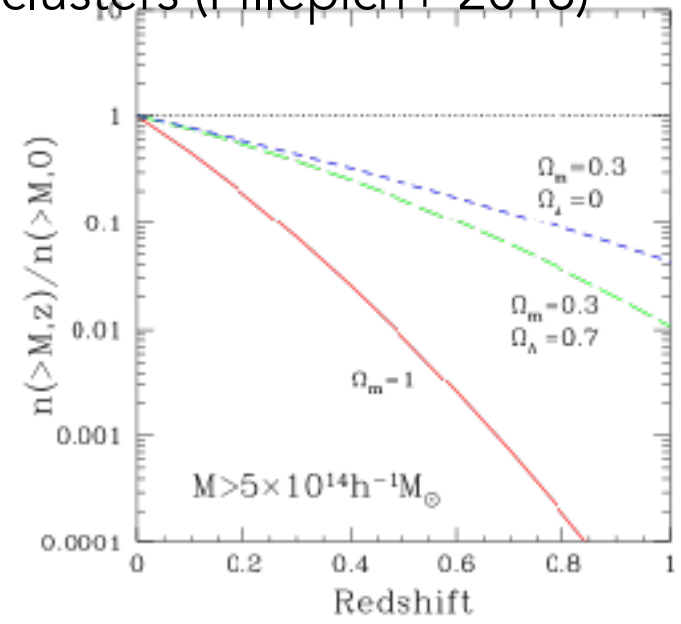
- SRG/eROSITA factsheet:
  - Scientific drivers
  - Technical characteristics and mission profile
- First 15 months of science operations
  - Mission status, operations
  - Highlights from early Performance Verification observations
  - The all-sky survey

(X-ray) Clusters Cosmology



The Virgo Collaboration; Jenkins et al. 1998

- Clusters are exponentially sensitive tracers of **growth of structures**
- A signature of clusters is the detection of hot (~10^7 K) X-ray ICM
- eROSITA (PSF, sensitivity) was designed to be able to detect >10^5 clusters (Pillepich+ 2018)



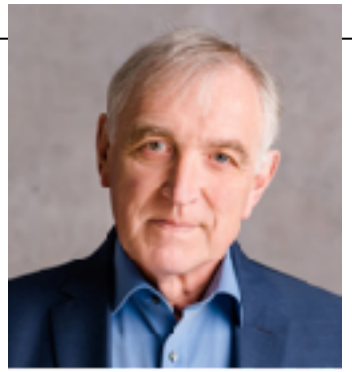
Rosati, Norman, Borgani 2002

Spektr-RG

Credit: Russians pace web

- Old Spektrum X: 1987-2003
- Soviet/Russian-led mission, with broad international cooperation (US, UK, Italy, Germany, Denmark, Israel, turkey)
- Did not survive funding crisis of Russian Space Science after collapse of Soviet Union

Rashid Sunyaev



Peter Predehl

- SRG developed since 2009 in the framework of Russian Federal Space Program for the Russian Academy of Sciences represented by IKI (Space Research Institute)
- Spacecraft designed by Lavochkin Association (NPOL) of the Roskosmos corporation

eROSITA on Spektr-RG

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

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

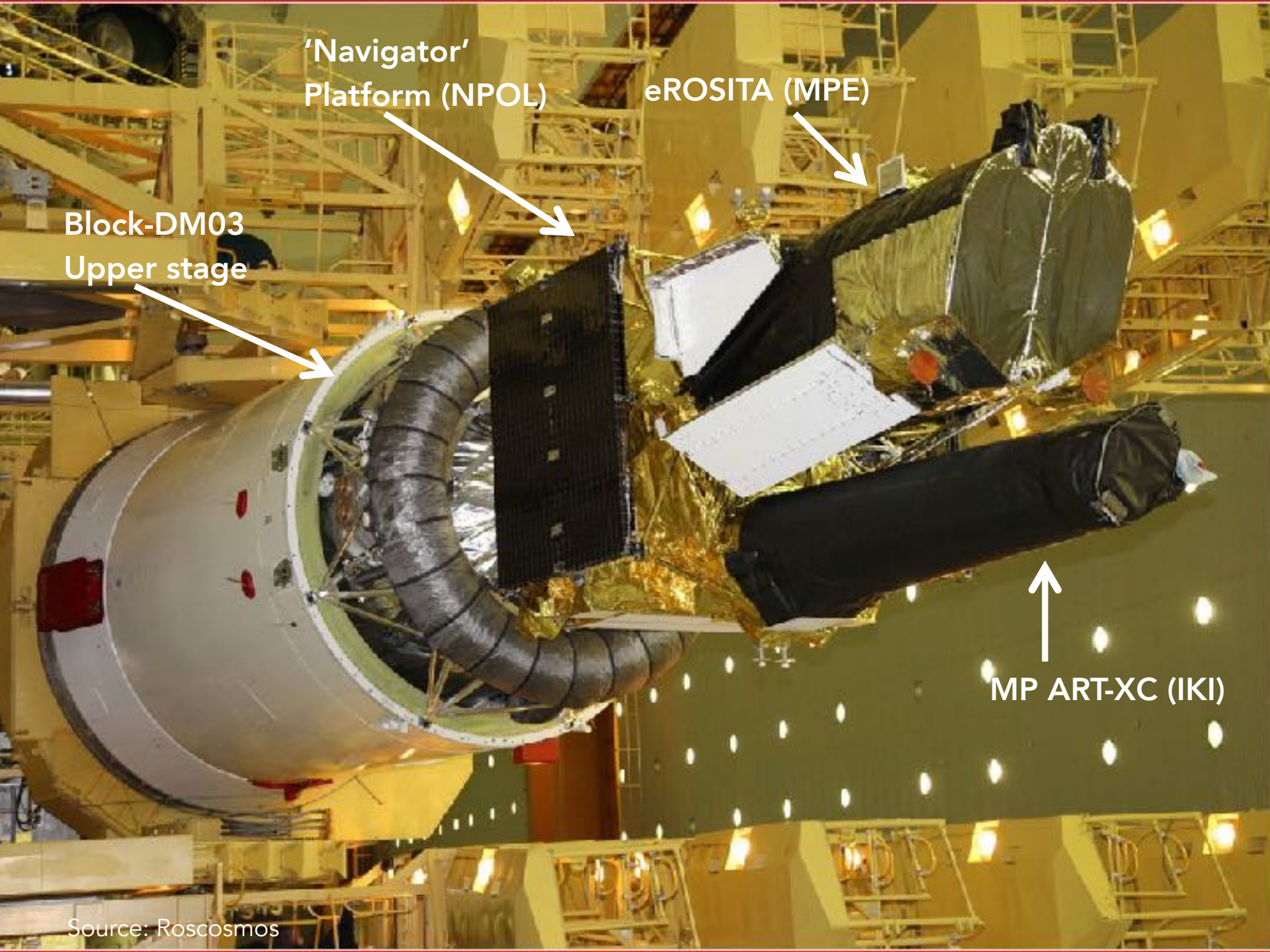
Associated Institutes:
MPA, Garching/D
IKI, Moscow/Ru
USM (Universität München)/D
AI[illegible])/D

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

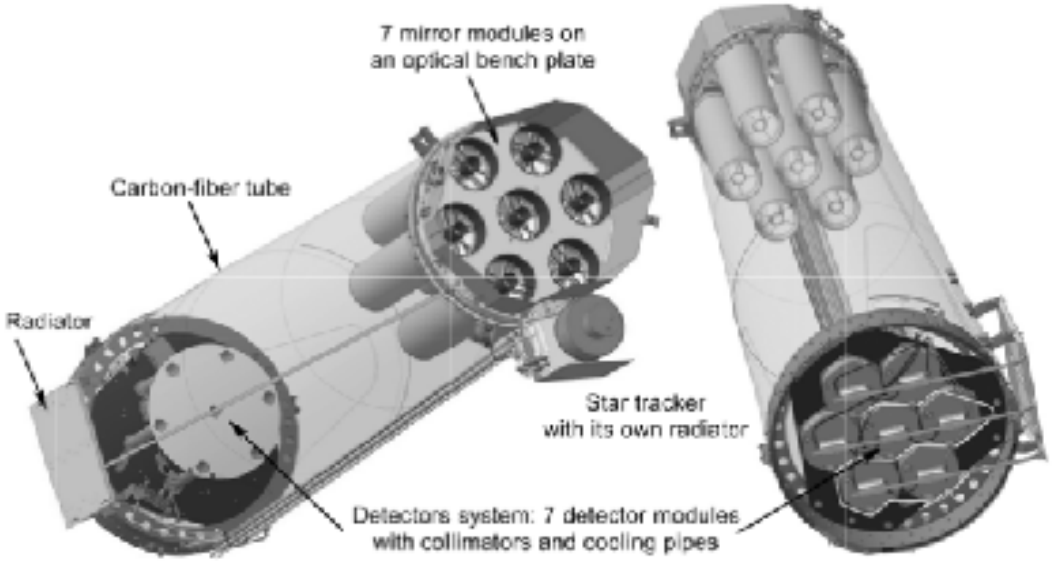
MPE: Scientific Lead Institute, Project Management
Instrument Design, Manufacturing, Integration & Test
Data Handling & Processing, Archive etc.

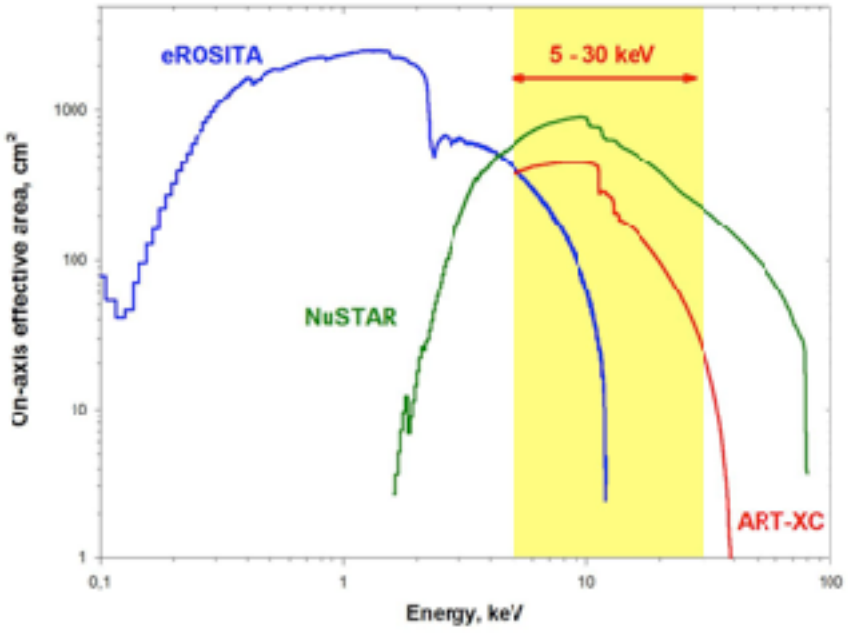


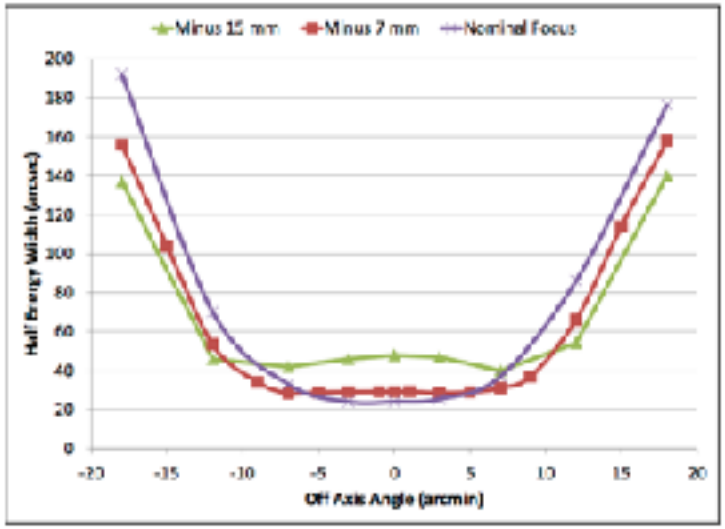
Source: Roscosmos

Mikhail Pavlinsky ART-XC

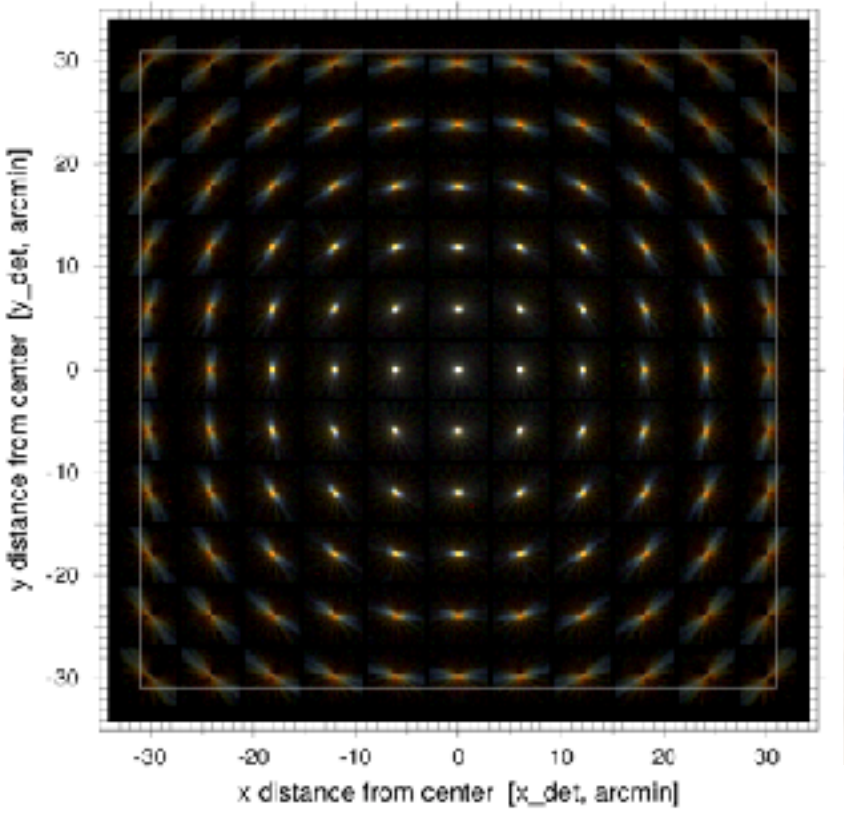
- Energy range: 5-30 keV
- FOV: ~34’
- On-axis resolution <1’
- CdTe detectors:
  - Energy resol. 10% at 14keV
  - Time res. 1ms







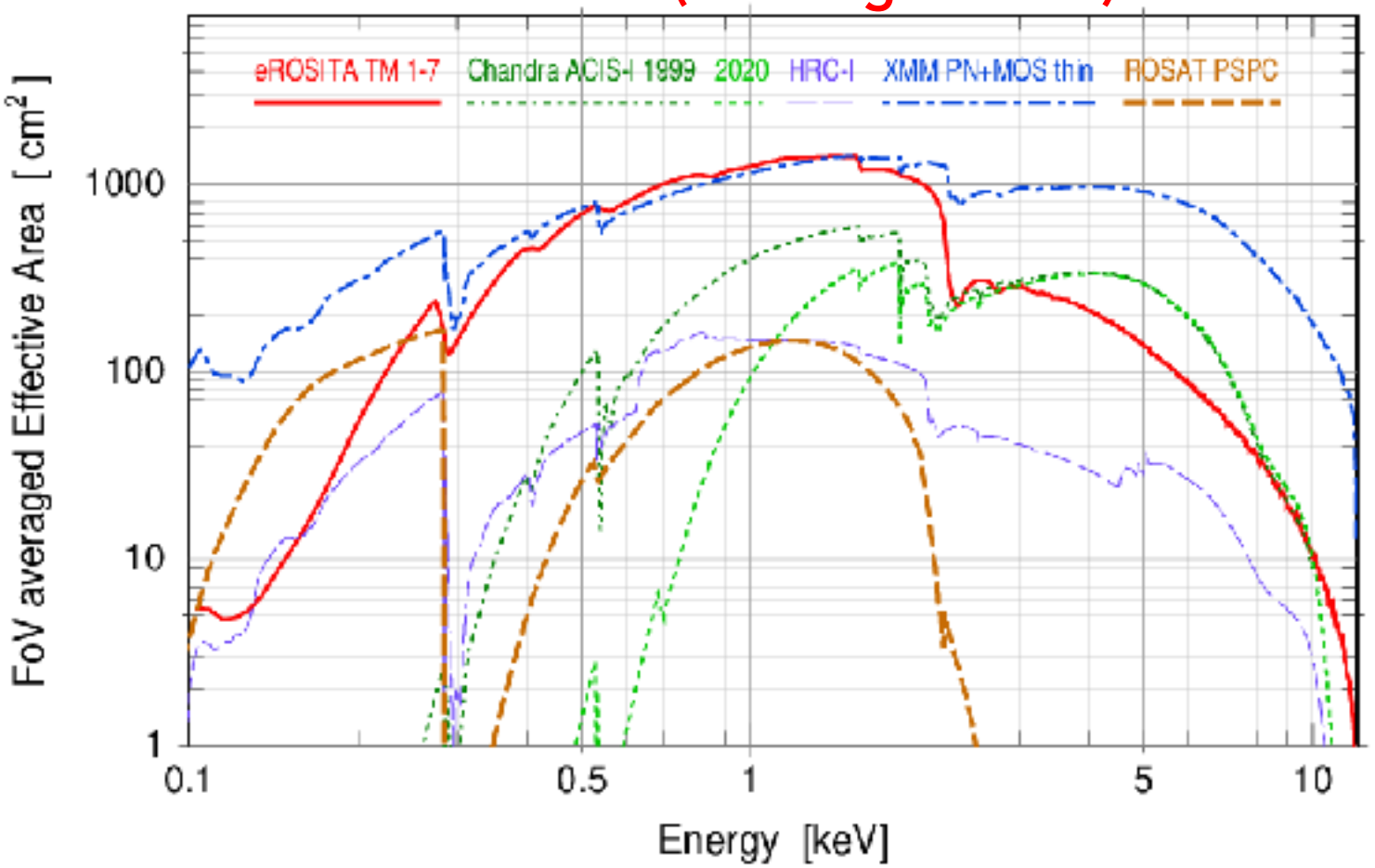
7 Mirrors + pnCCDs



- Focal length: 1.6 m. **Field of view: 1 degree (diameter)**
- Half-Energy width **(HEW) ~18" (on-axis, point.); ~26" (FoV avg., survey)**
  - Point-source positional accuracy ~4"-5"
- X-ray baffle (10µm precision alignment): 92% stray light reduction
- pnCCD with Framestore (no 'out of time' events), **no chip gaps**
- Extremely **good detector uniformity, little Temperature dependence**
- **Spectral resolution** at all measured energies within specs (**~80eV @1.5keV**)

Large Effective Area

~1300 cm² (FoV avg. @1keV)



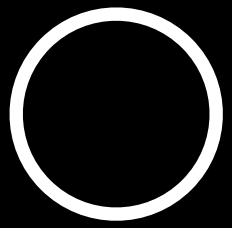
- Effective area at 1keV comparable with XMM-Newton
- Factor ~5-6 larger surveying speed

eROSITA's advantage

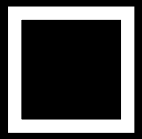
Grasp @1keV:
- 5×XMM-Newton
- 100×Chandra ACIS today
- 4 years fully dedicated to all-sky survey

Moon diameter
30 arcmin

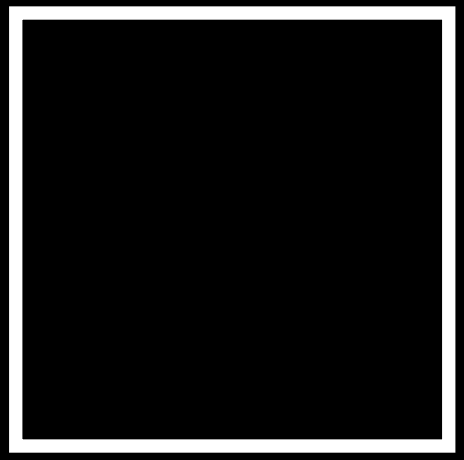
XMM-Newton
Field of view ~ 30 arcmin



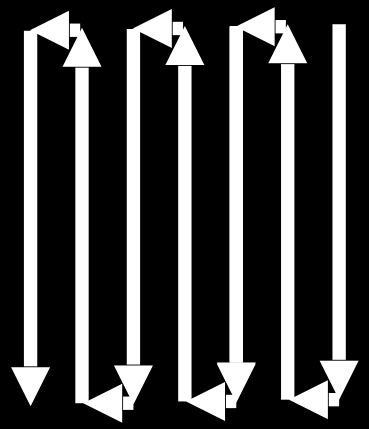
Chandra
Field of view ~ 17 arcmin



eROSITA
Field of view ~ 62 arcmin



+

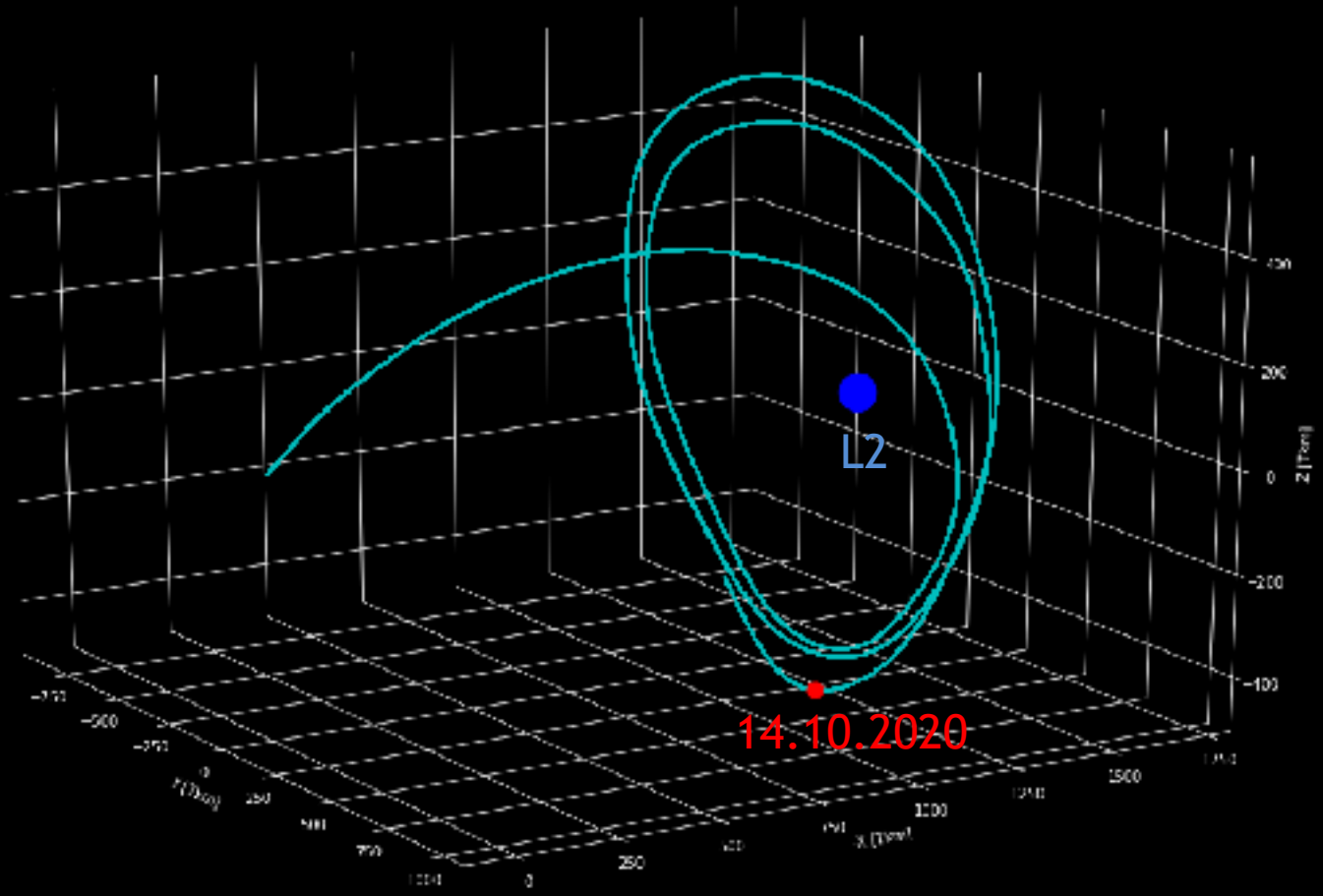


Scanning feature

Baikonur, July 13th, 2019

Source: Roscosmos

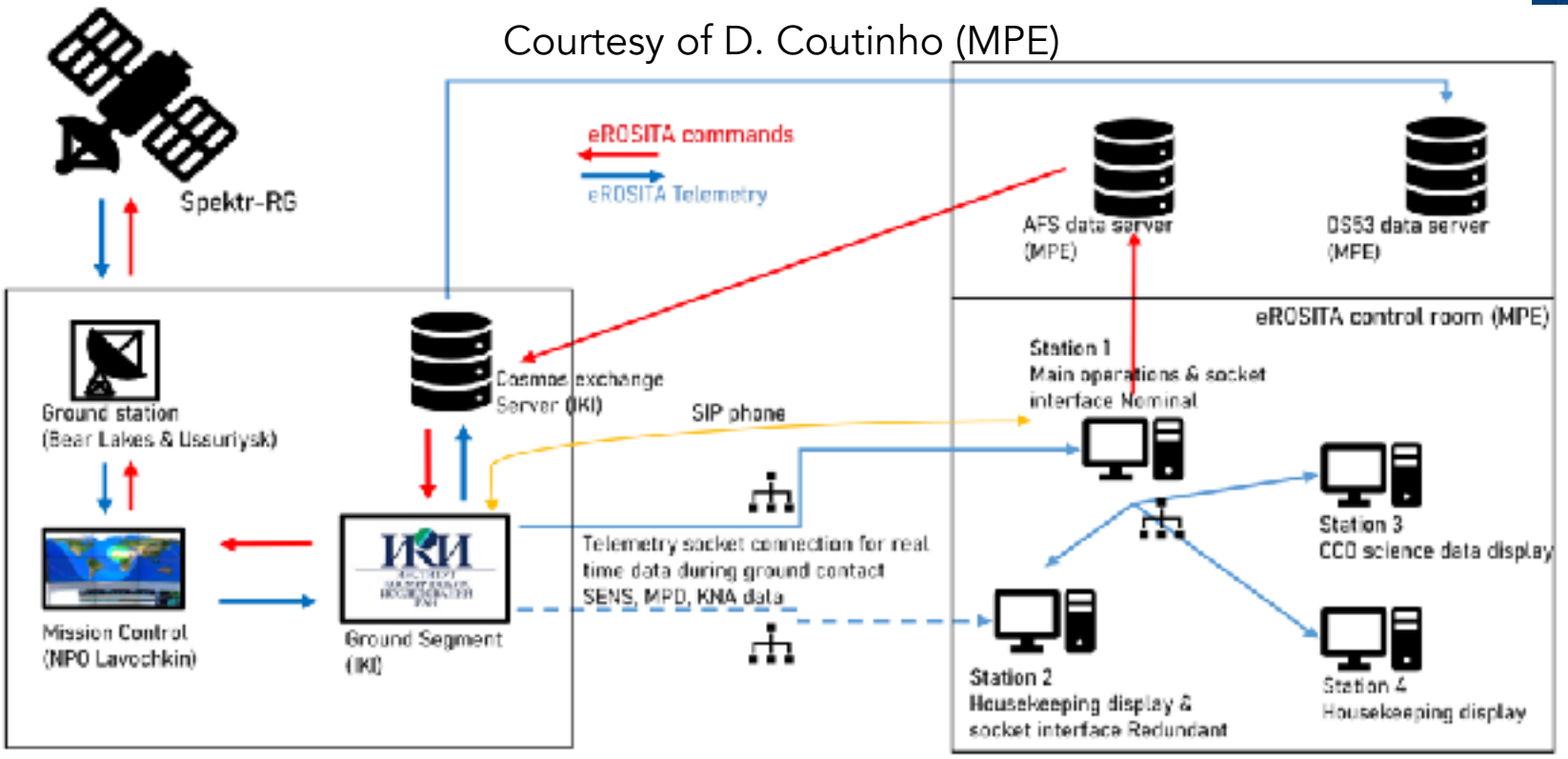
A large Halo L2 orbit

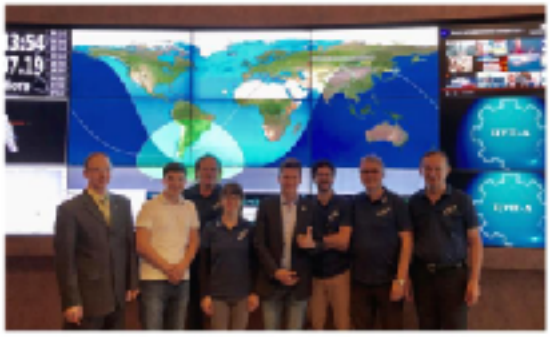


Picture: P. Predehl, MPE

SRG/eROSITA Operations

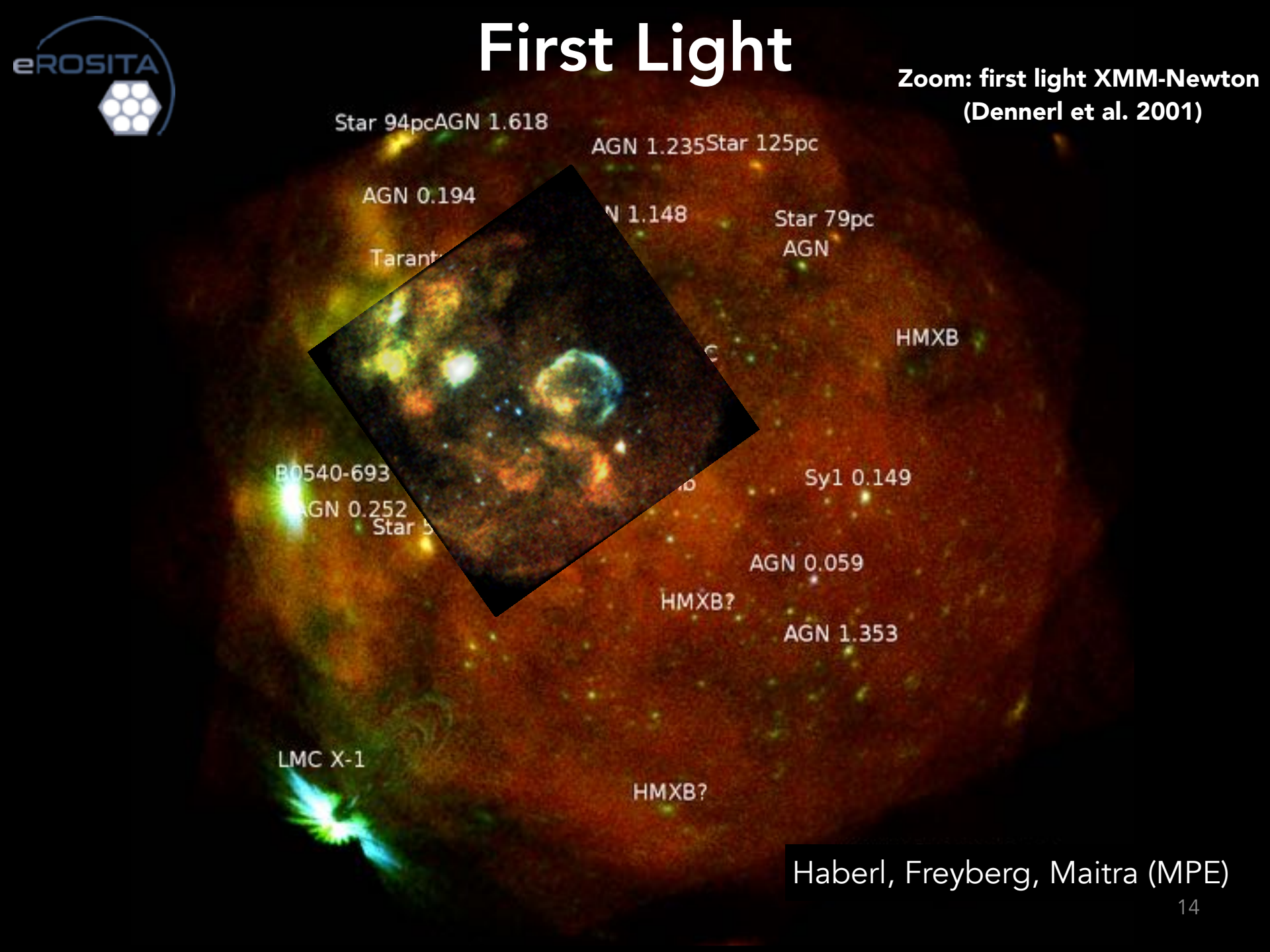
Courtesy of D. Coutinho (MPE)





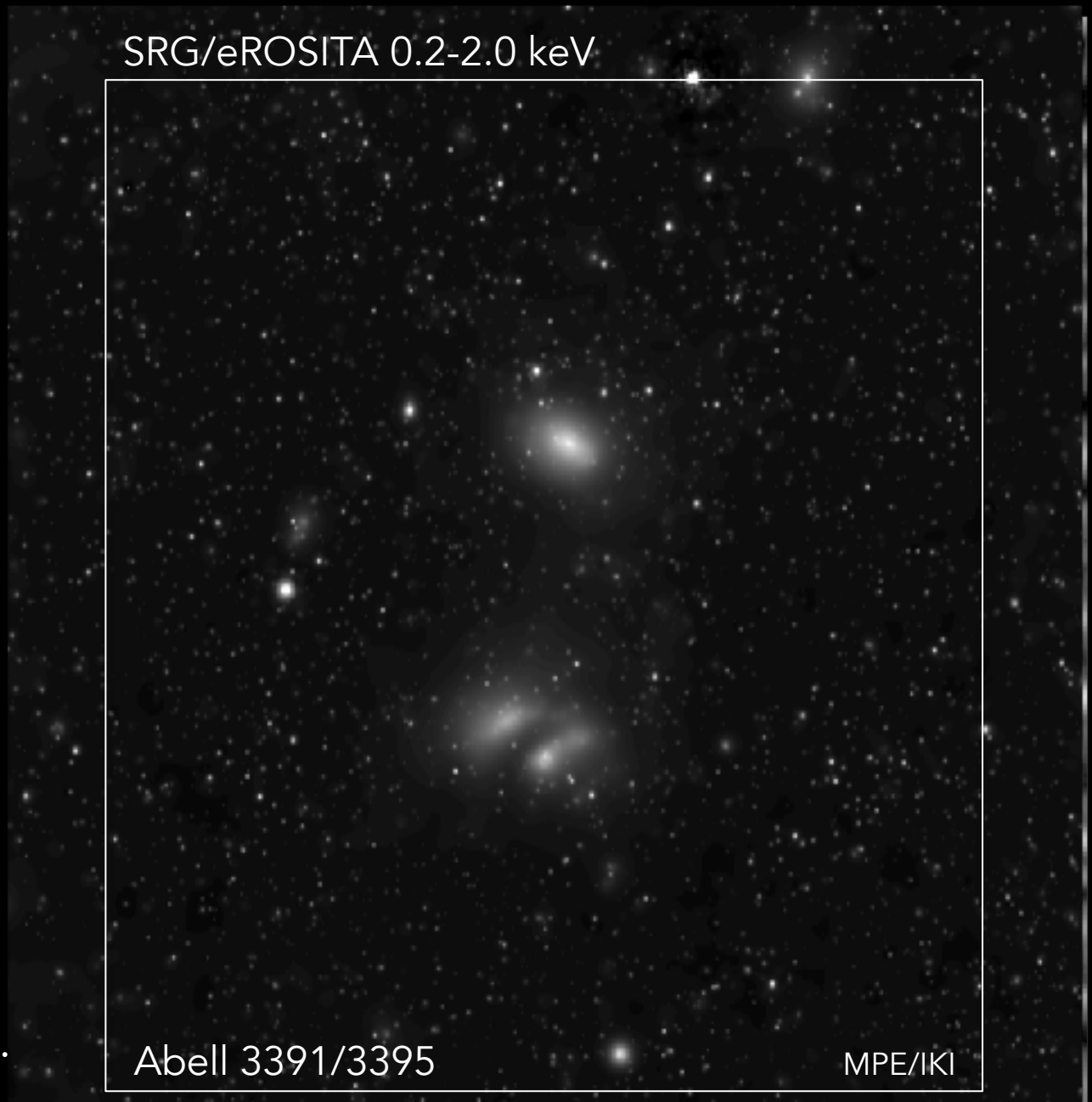
First Light

Zoom: first light XMM-Newton (Dennerl et al. 2001)



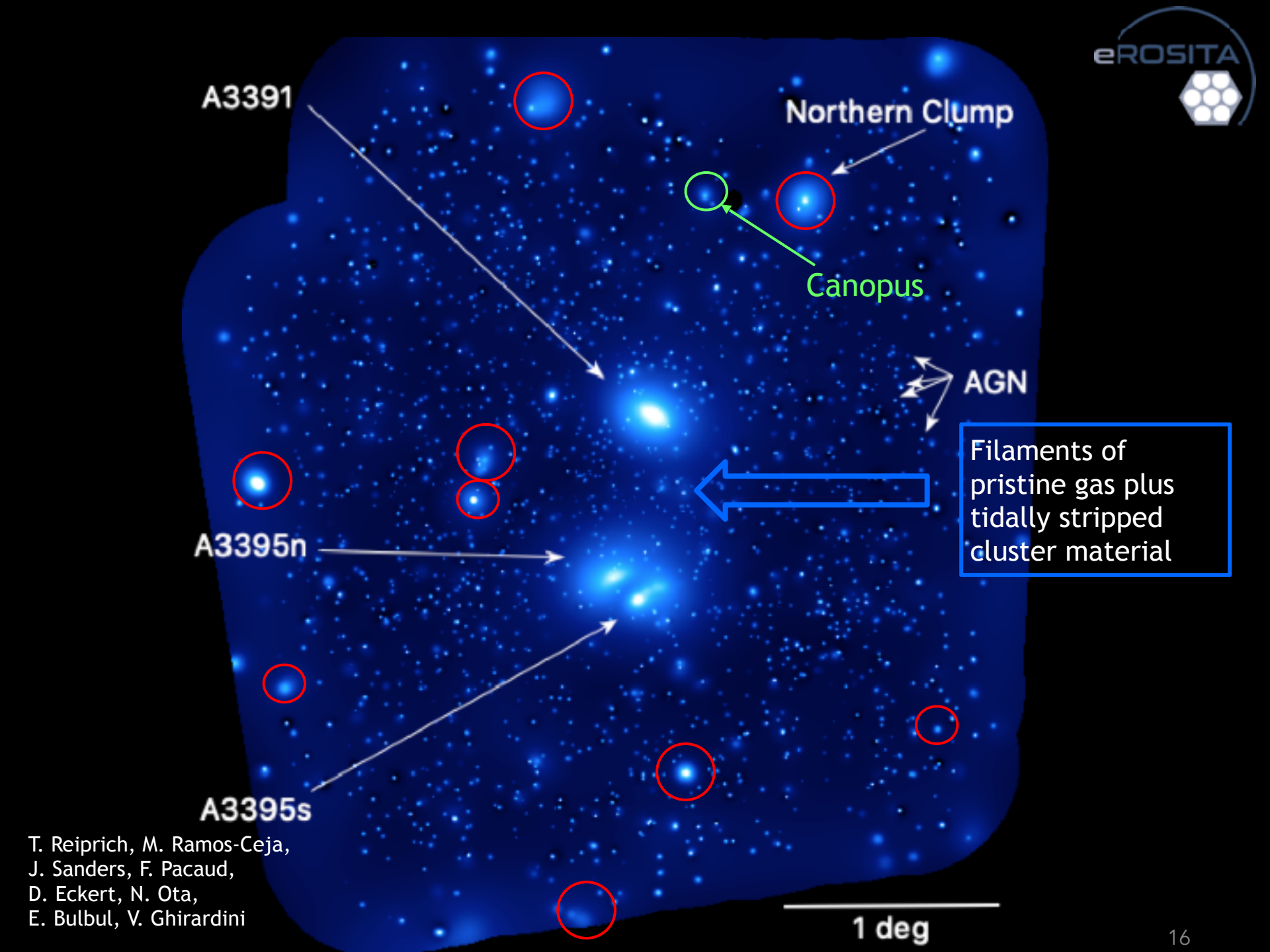
Haberl, Freyberg, Maitra (MPE)

PV phase: A3391/A3395



XMM-Newton
0.4-1.25 keV

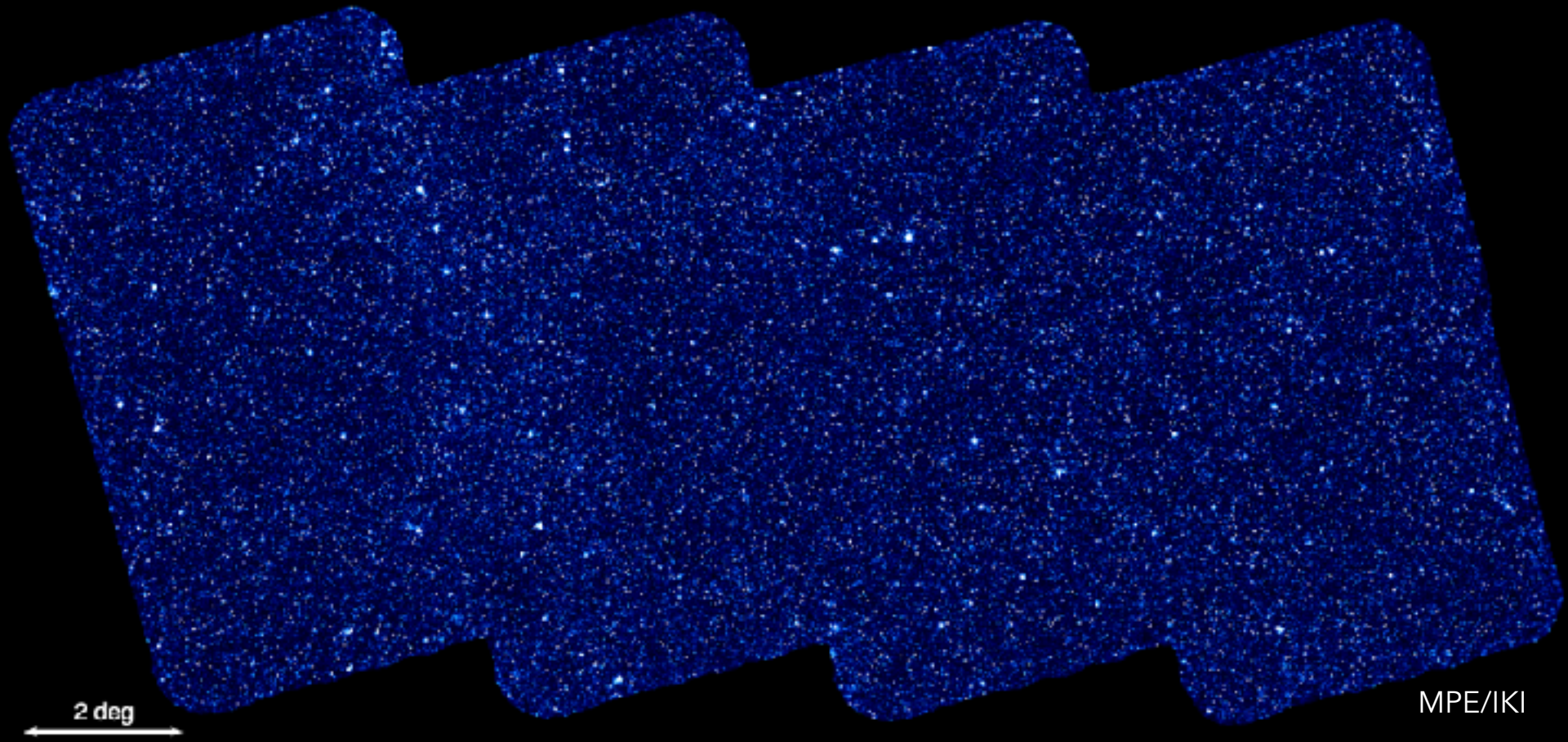
Reiprich et al.



T. Reiprich, M. Ramos-Ceja,
J. Sanders, F. Pacaud,
D. Eckert, N. Ota,
E. Bulbul, V. Ghirardini

eFEDS: a sky preview at the final survey depth

140 deg²; ~2.5ks exposure; Brunner, Lamer, Liu et al., in prep.

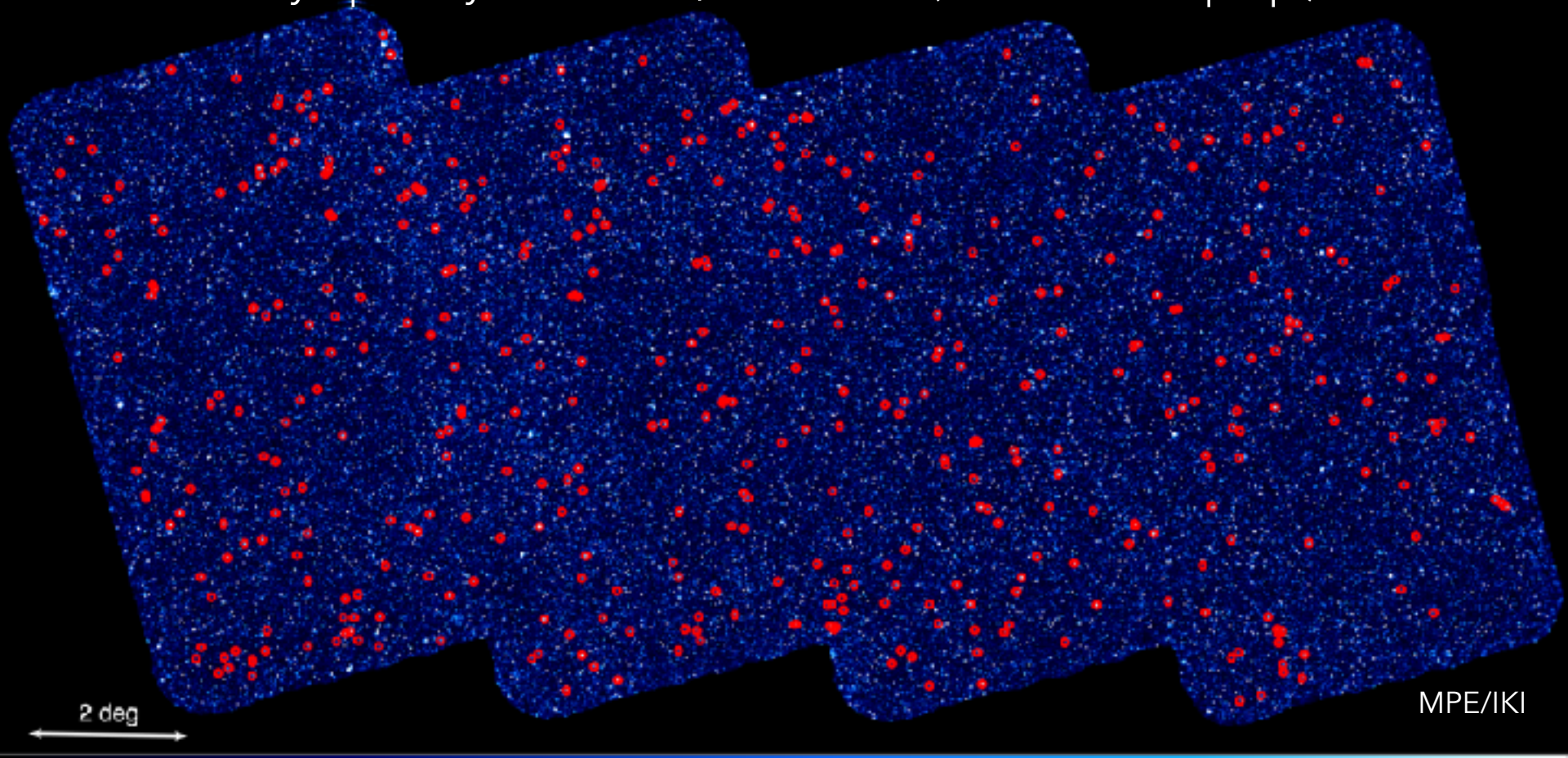


Credit: H. Brunner, M. Ramos-Ceja

Exposure corrected image in the 0.5–2.0 keV band

eFEDS Clusters

542 galaxy clusters detected by eROSITA (Liu, Bulbul et al. in prep.)
~ 440 already optically confirmed, 0.1<z<1.1 (Klein et al. in prep.)



Credit: H. Brunner, M. Ramos-Ceja

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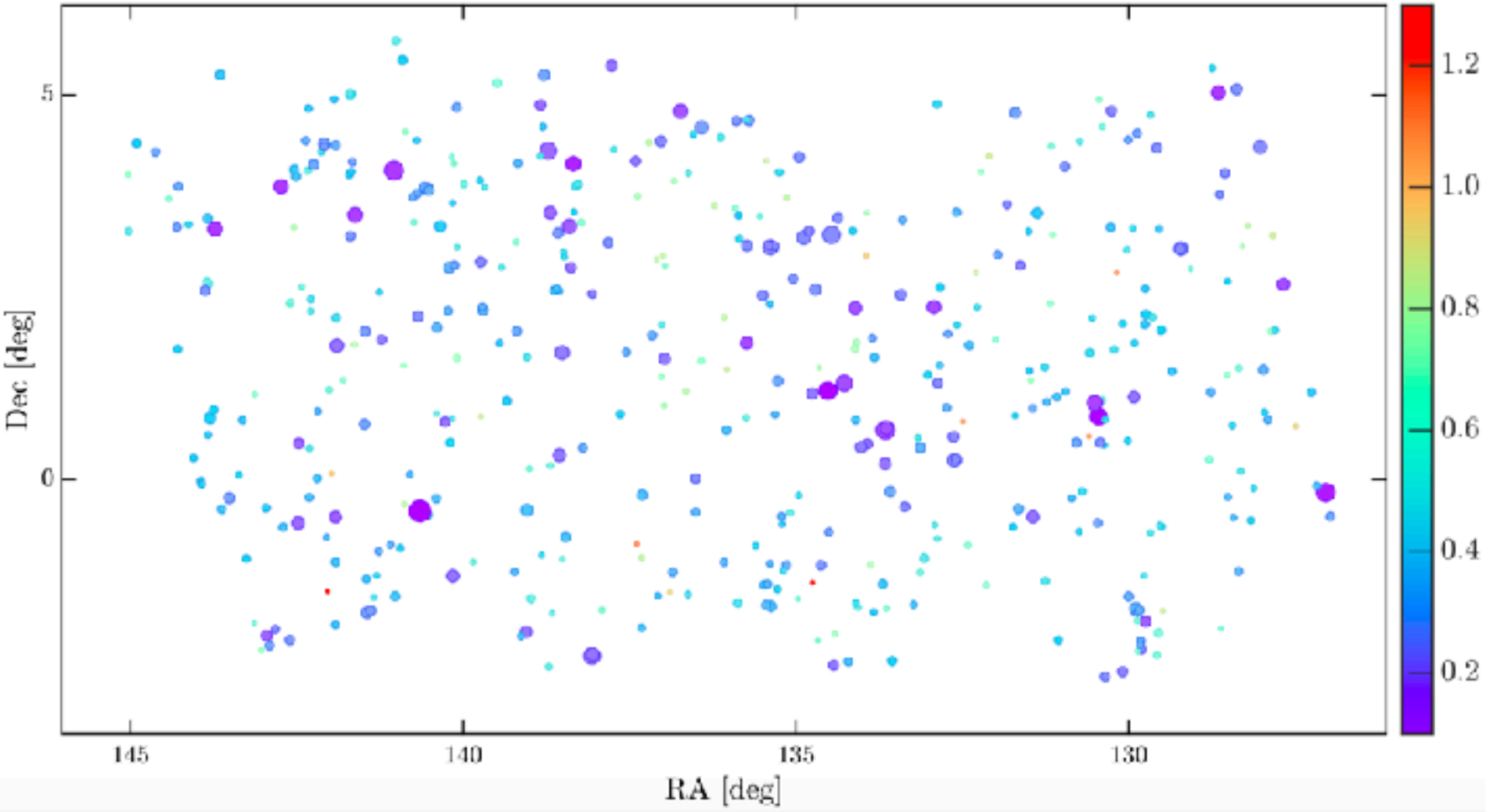
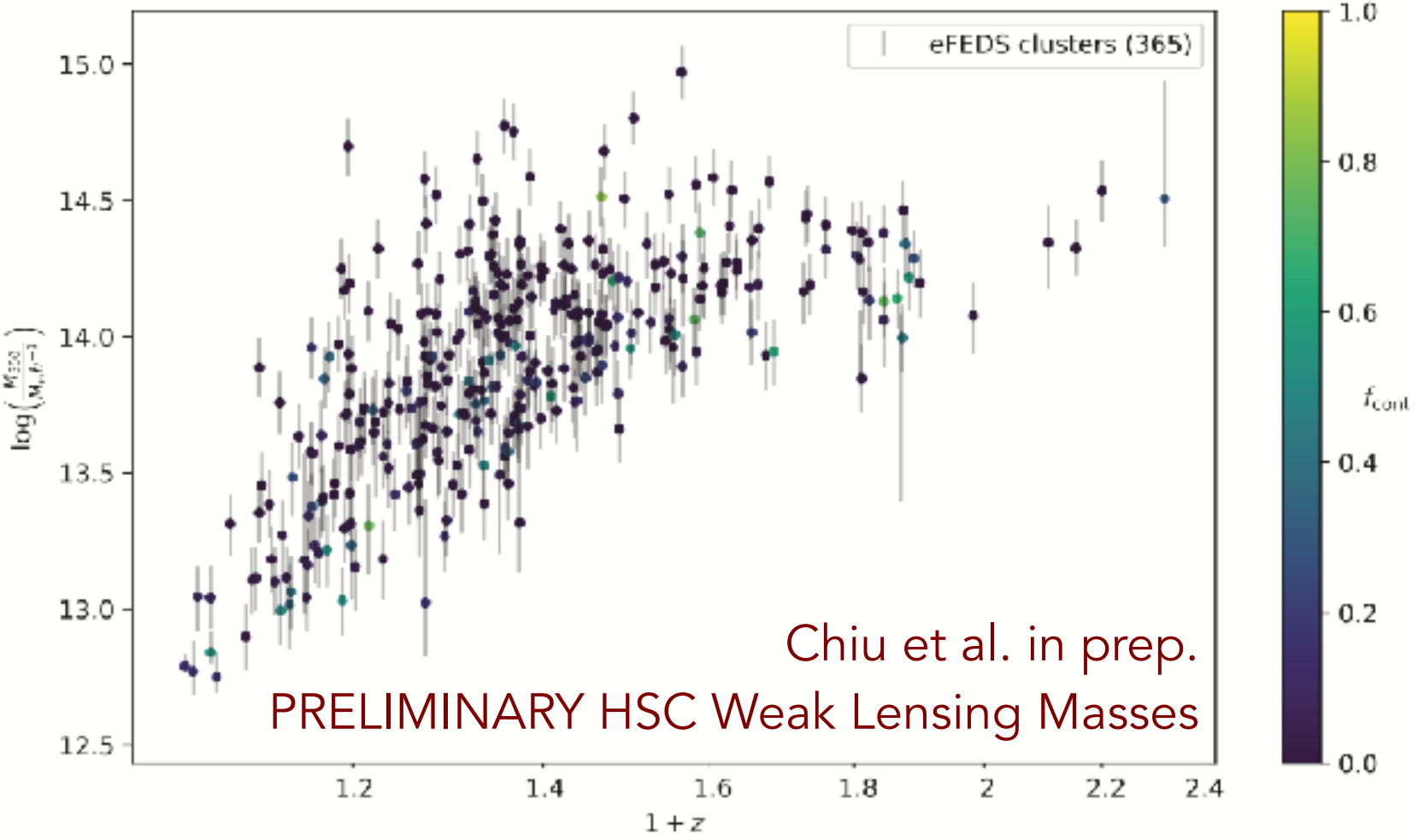


eFEDS Clusters

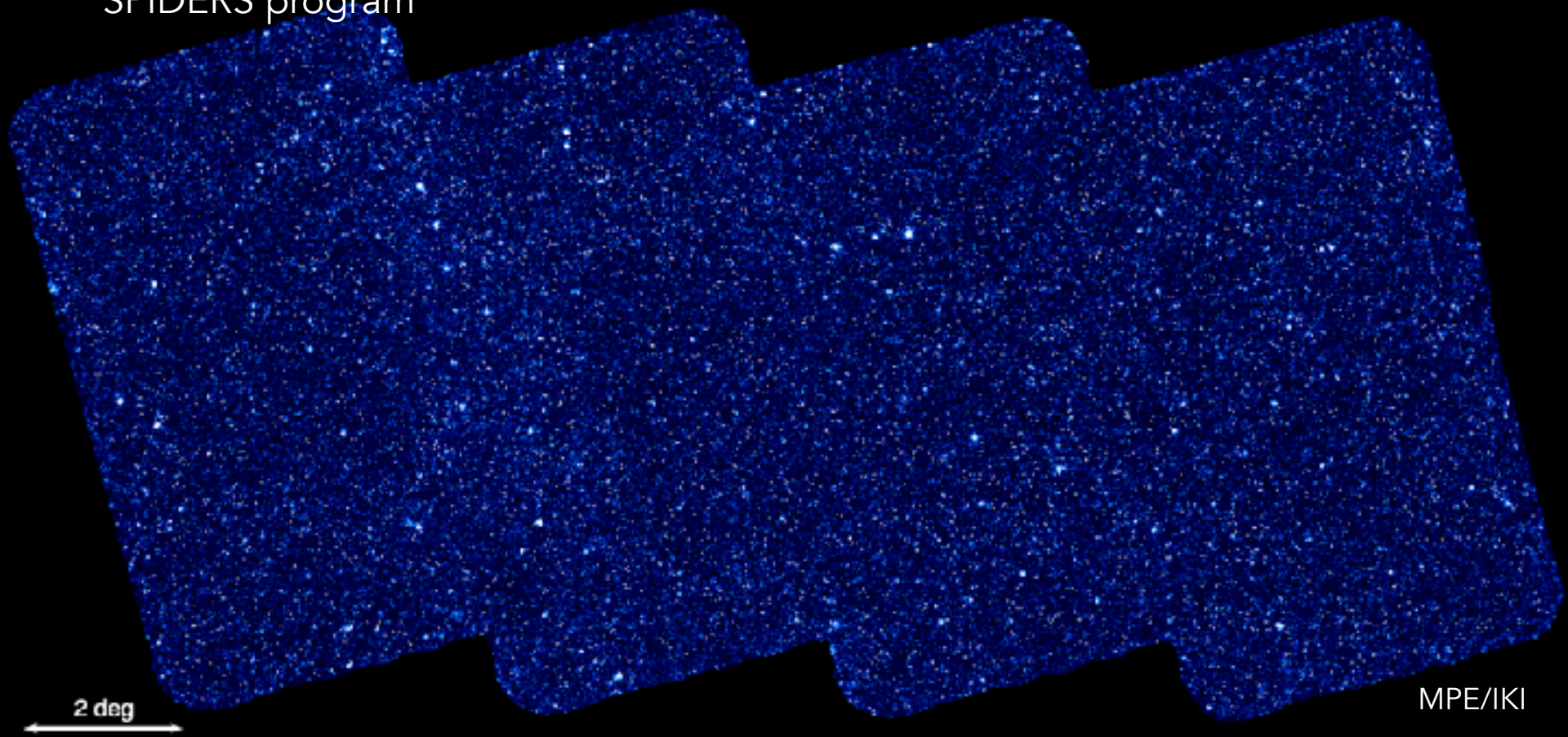
542 galaxy clusters detected by eROSITA (Bulbul et al. in prep.)

~ 339 already optically confirmed, 0.1<z<1.1 (Klein, Mohr et al. in prep.)



eFEDS AGN

- More than 25k point-sources detected (Salvato et al. In prep.)
- ~8000 spectroscopic redshifts, including ~3800 from a dedicated SDSS-IV/ SPIDERS program

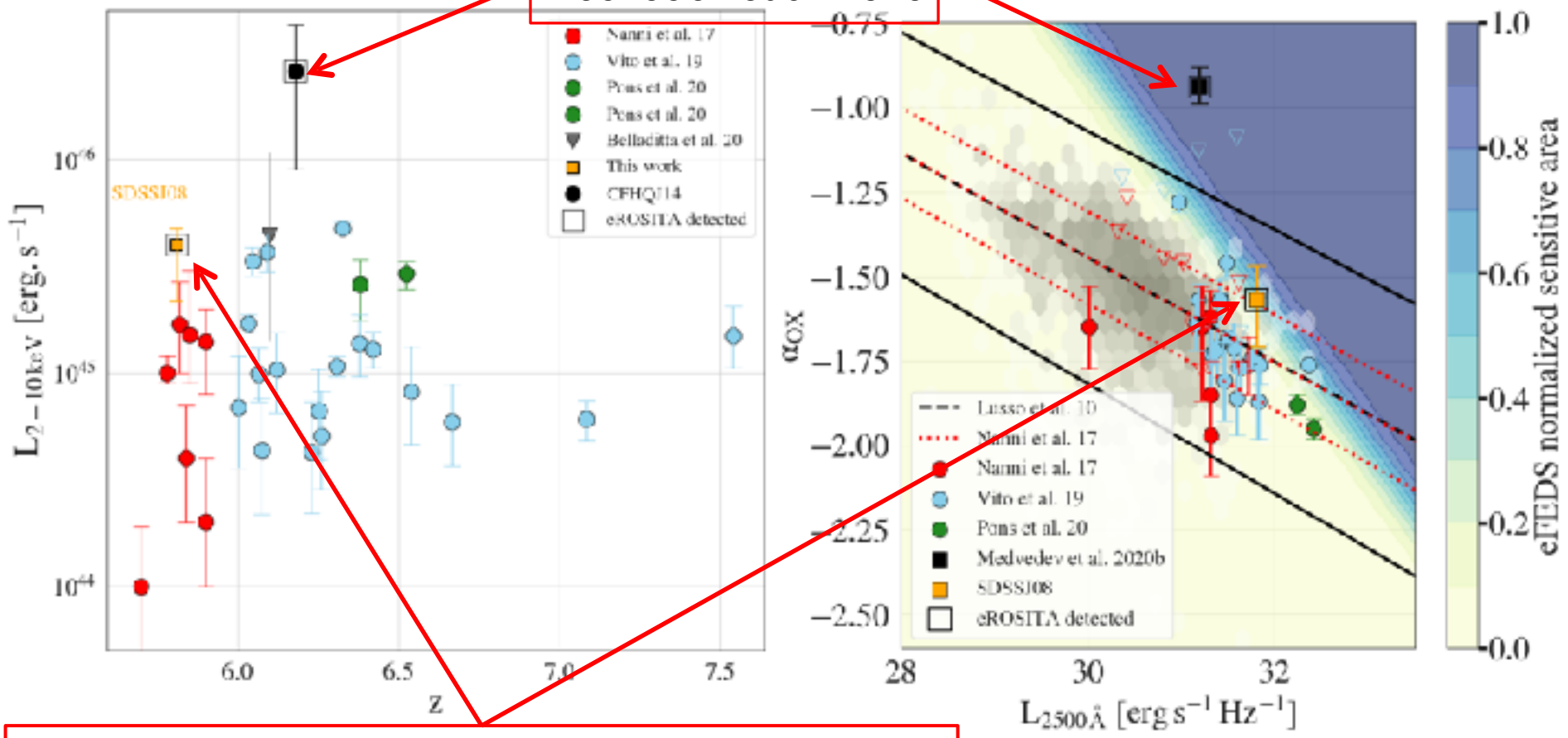


Credit: H. Brunner, M. Ramos-Ceja

Exposure corrected image in the 0.5–2.0 keV band

Blind detection of high-z QSO

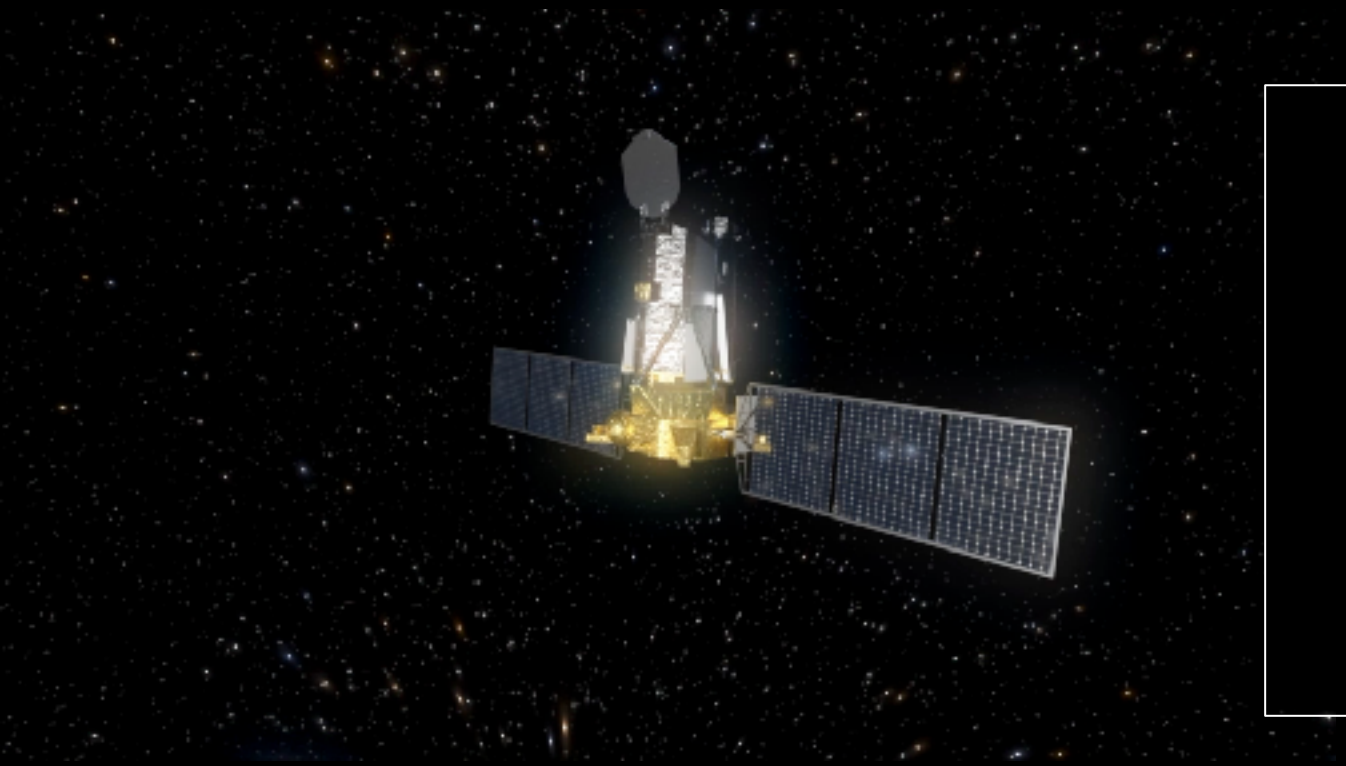
Medvedev et al. 2020

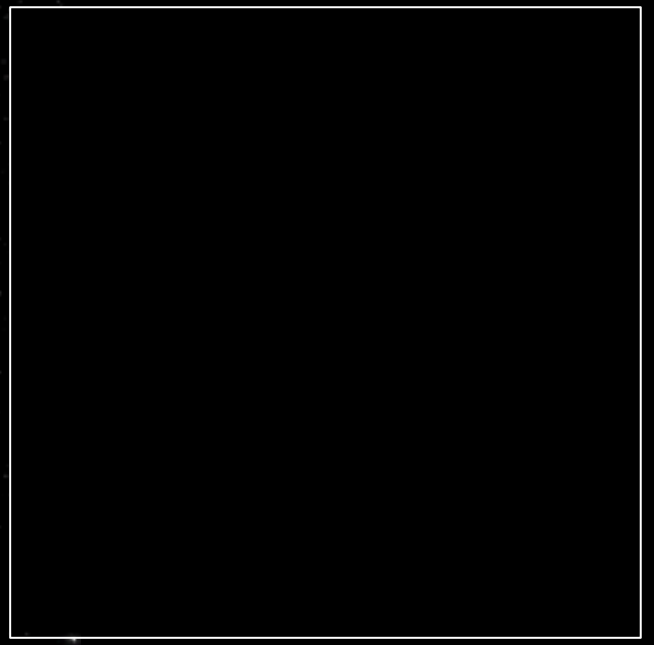


One z=5.81 (known) QSO detected in eFEDS: The second highest redshift X-ray 'blind' detection

Wolf et al. submitted

SRG: all-sky survey



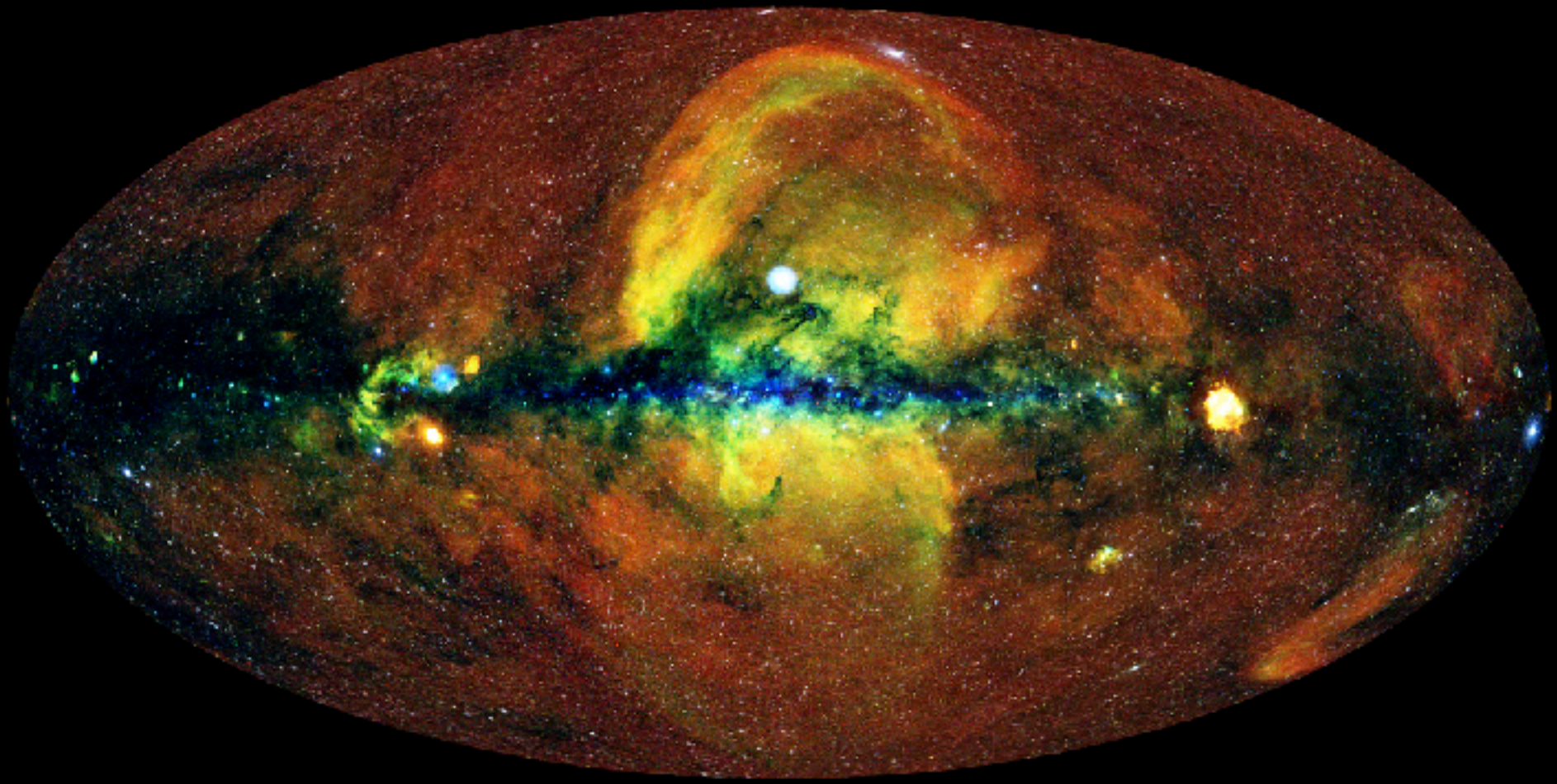


- **4 years**: 8 all sky surveys (eRASS:1-8; scanning mode: 6 rotations/day)
- **2.5 years**: pointed observations, including TBD GTO quota. 1 AO per year

eRASS:1, The first All-Sky Survey

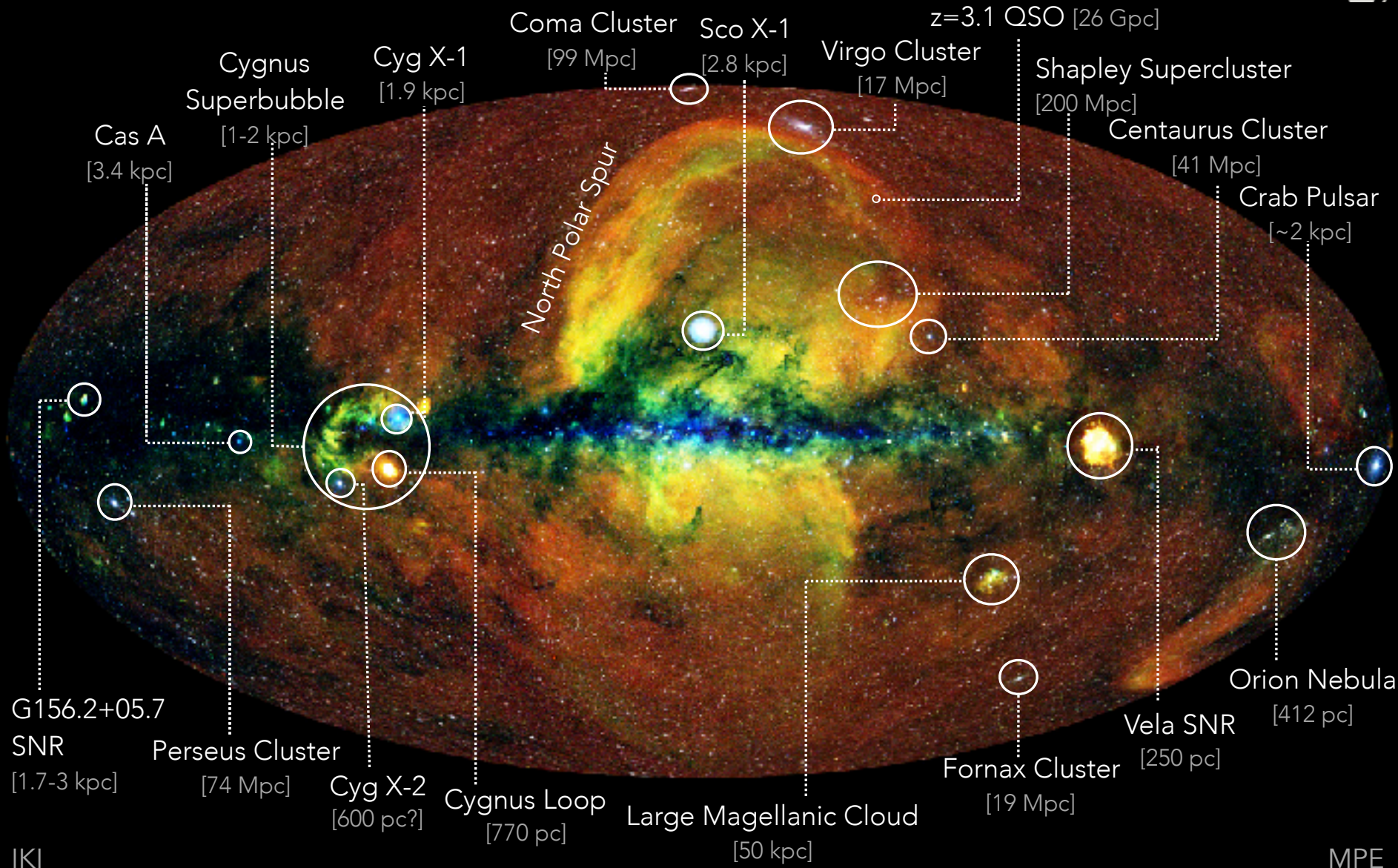
- Started on Dec. 12, 2019; completed on June 11, 2020
- Uniform exposure ~200s; up to 36ks at the Ecliptic Poles
- Typical sensitivity:
  - ~5x10^{-14} erg/s/cm^2 [0.3-2.3 keV]
  - ~ 7 x 10^{-13} erg/s/cm^2 [2.3-8 keV]
- Very few background flares, flexible mission planning: no gaps in exposure
- ~400 Million 0.12-5keV calibrated photons
- About 1 Million sources detected (~80% AGN; 20% Stars)
  - Almost double the number of known X-ray sources
- ~20k clusters, up to z~1
- Numerous transients discovered; fine tuning vetting mechanisms, followup resources

SRG/eROSITA 0.3-2.3 keV - RGB Map



IKI J. Sanders, H. Brunner (MPE), E. Churazov, M. Gilfanov (IKI), and eSASS team MPE

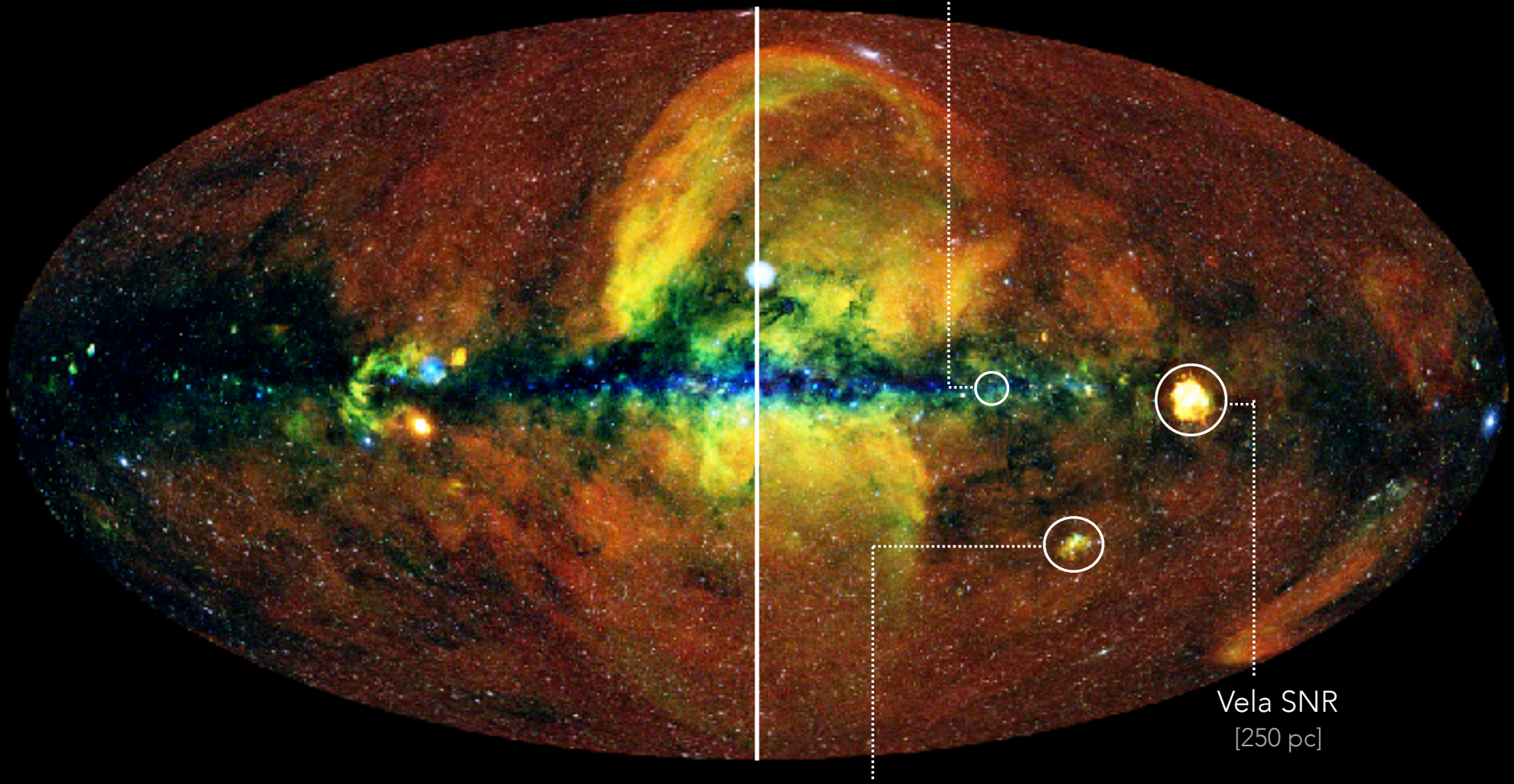
Navigating the eROSITA X-ray sky



IKI

MPE

A few highlights from eRASS:1



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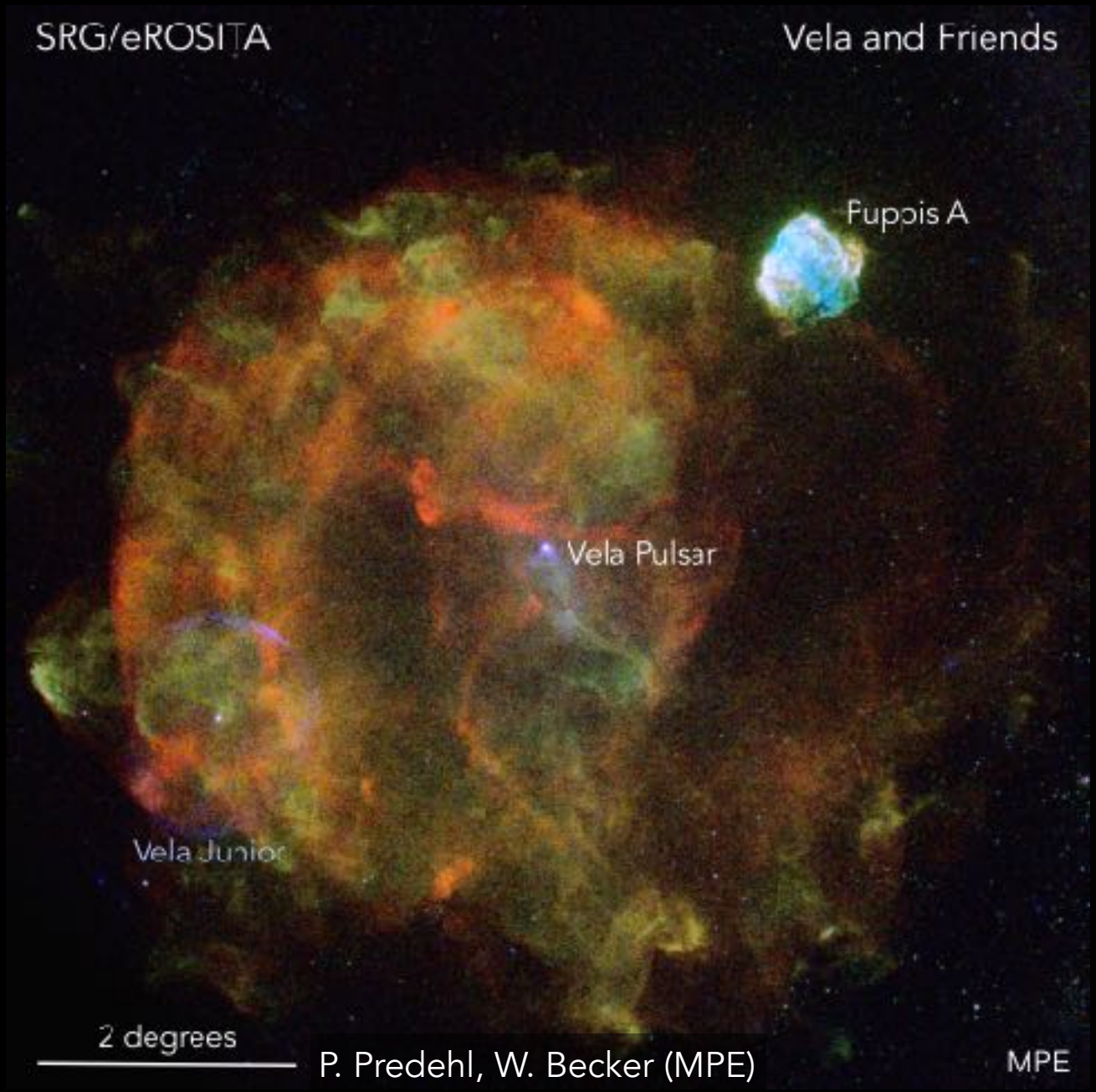
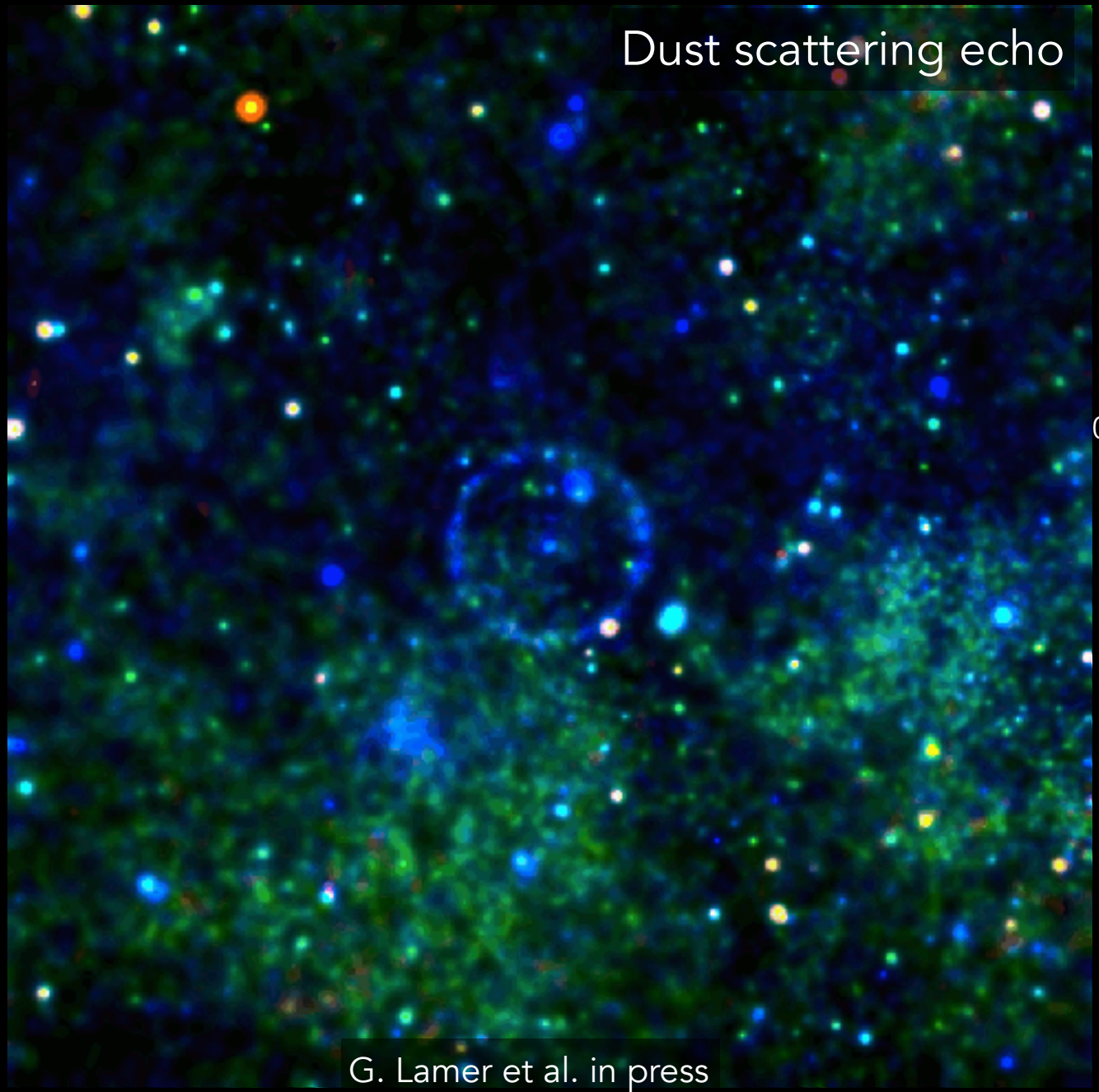
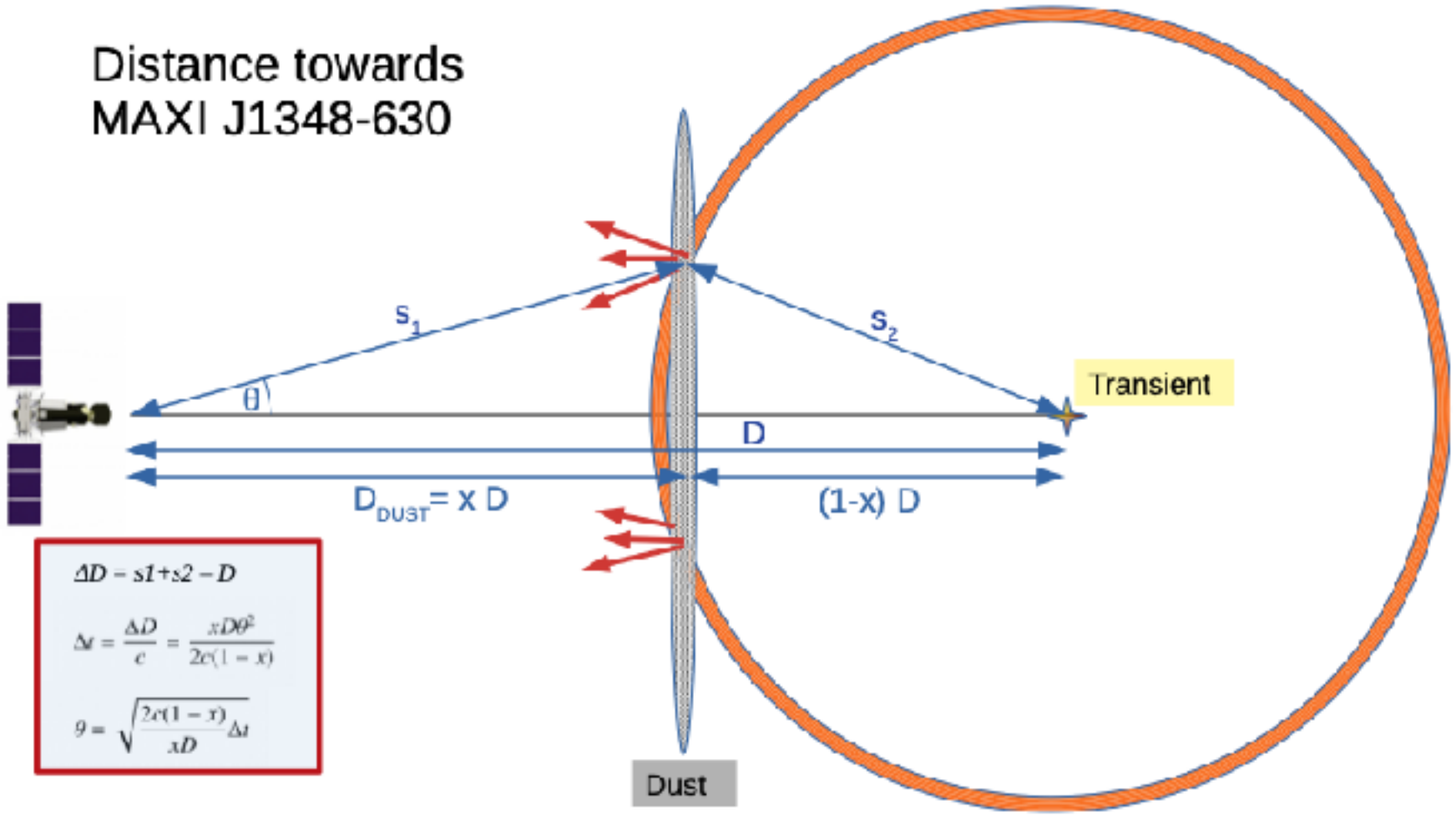

SRG/eROSITA
Vela and Friends
Puppis A
Vela Pulsar
Vela Junior
2 degrees
P. Predehl, W. Becker (MPE)
MPE

Dust scattering echo



G. Lamer et al. in press

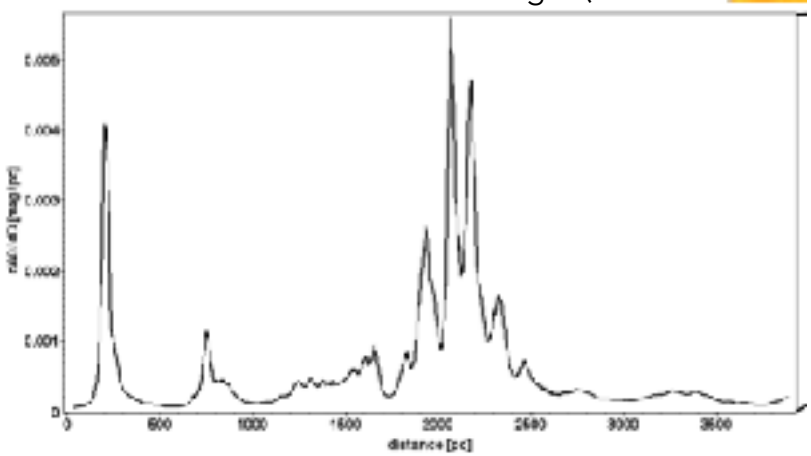
Dust scattering ring

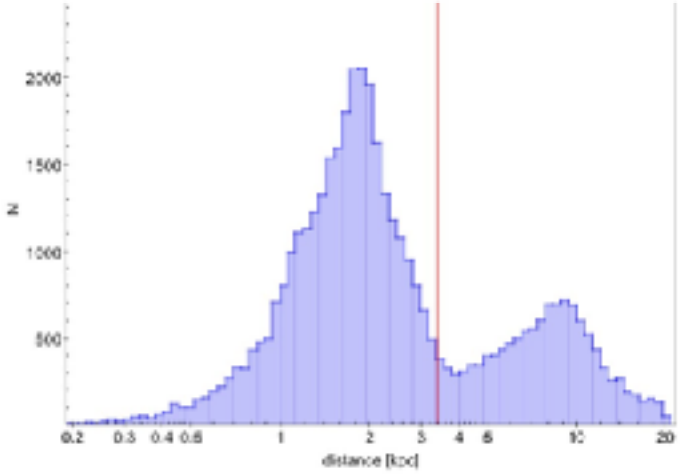


G. Lamer et al. A&A in press

Precise distance to BH

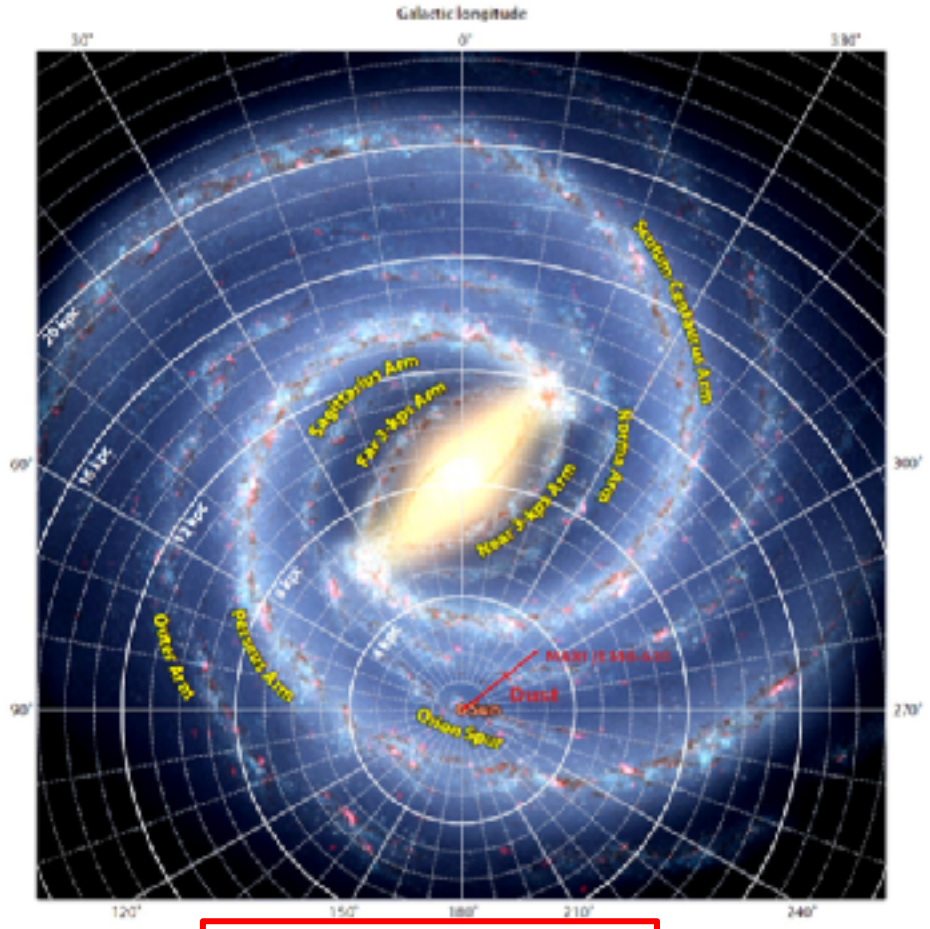
Differential extinction on the line of sight (Lallement+ 2019)





Distance of MAXI J1348−630 (red) compared to the distribution of distances in the Gaia stars along the LoS

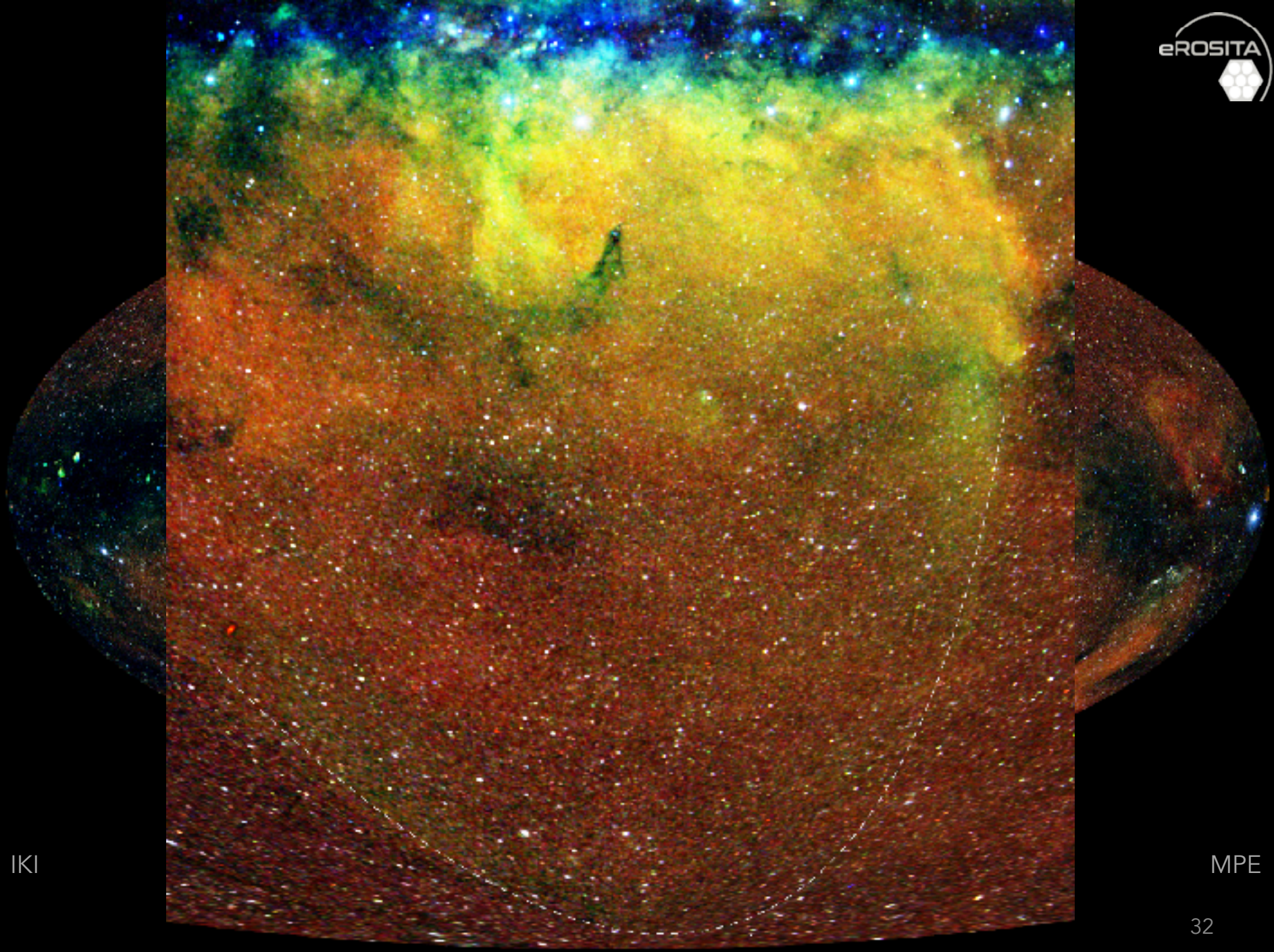
G. Lamer et al. A&A in press



M_{BH} =13 +- 2 $M_\odot$

L_{peak} ~ 0.1 L_{edd}

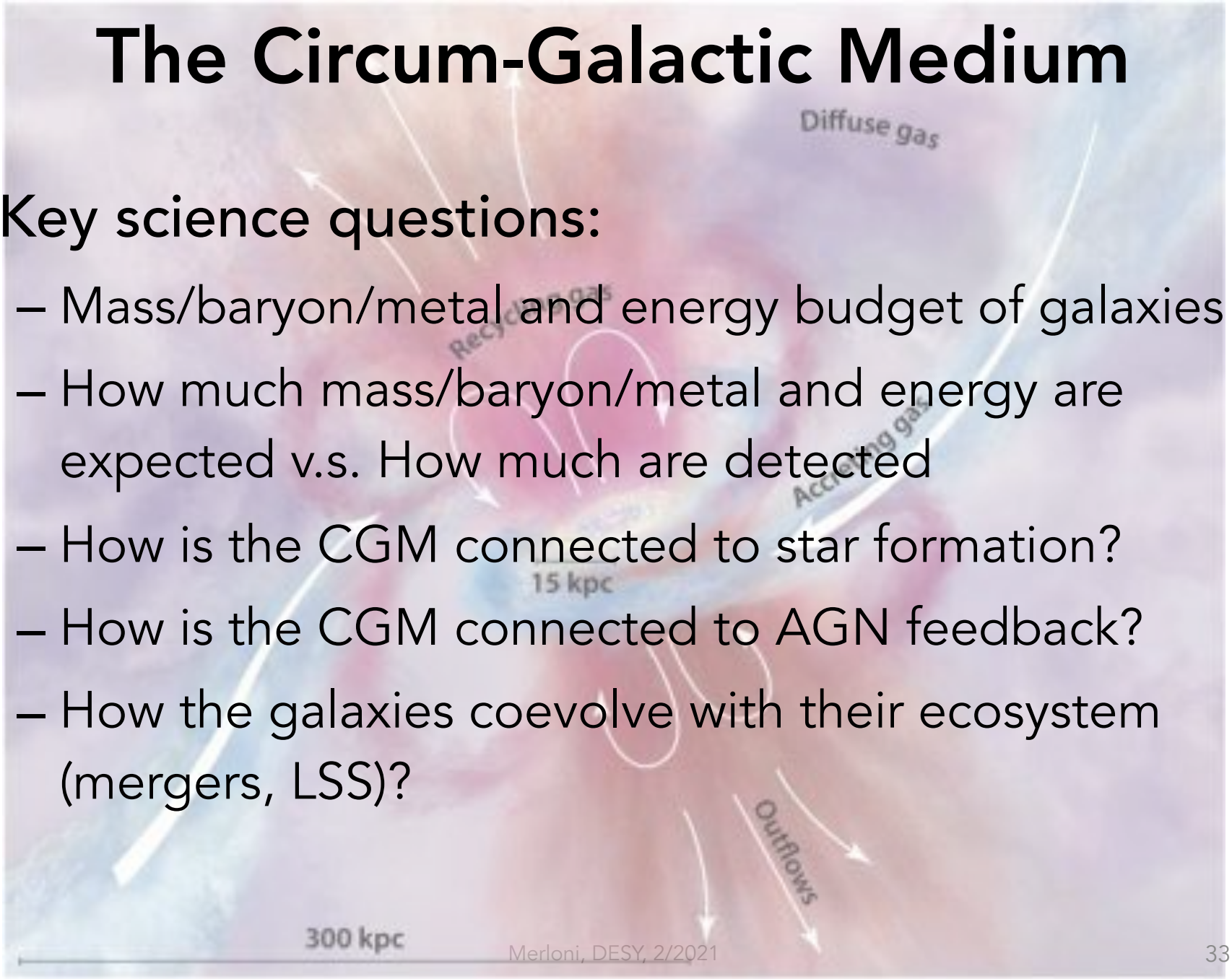
$L_{transition}$ ~ 0.017 L_{Edd}



IKI

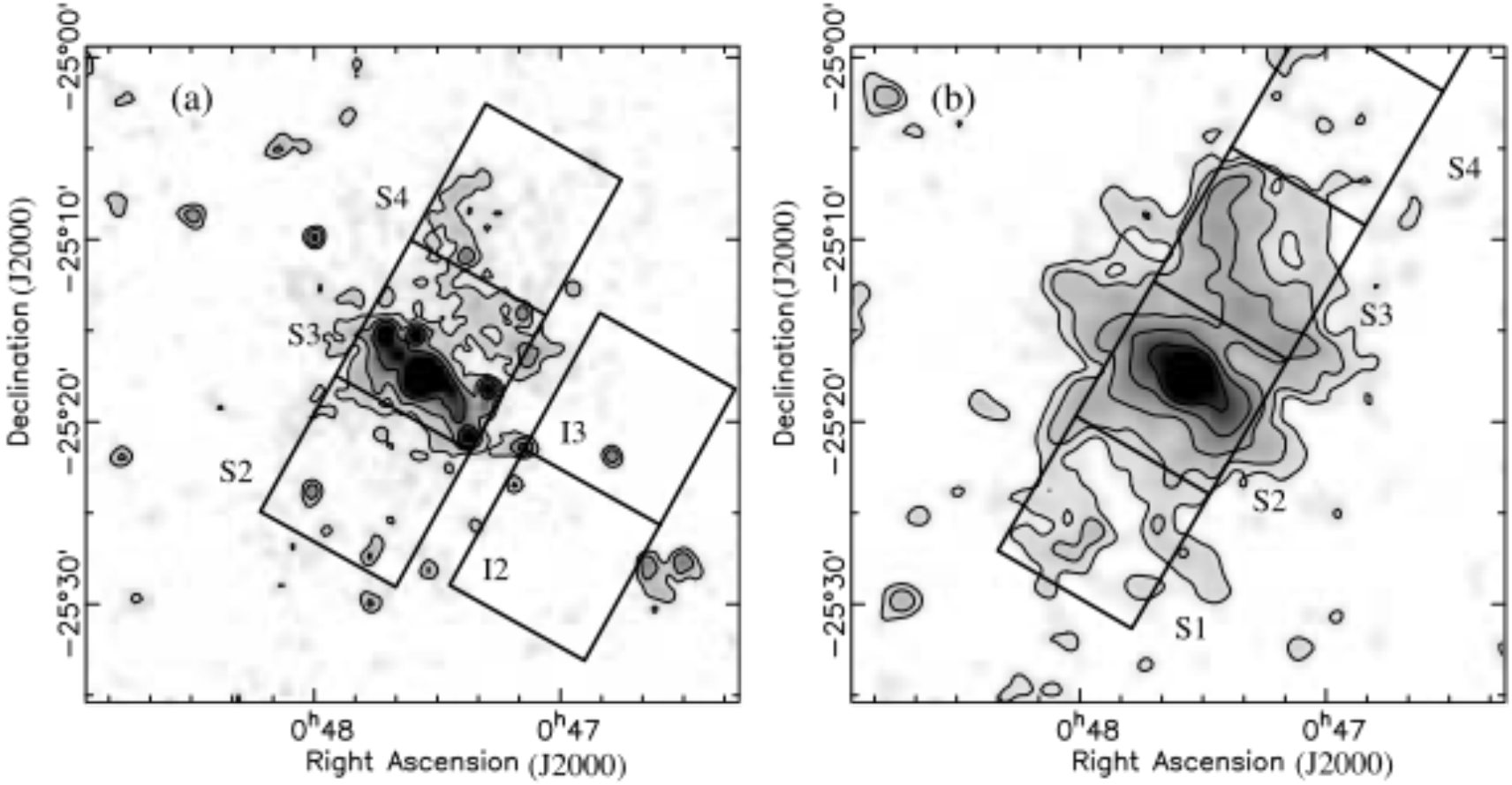
MPE

The Circum-Galactic Medium



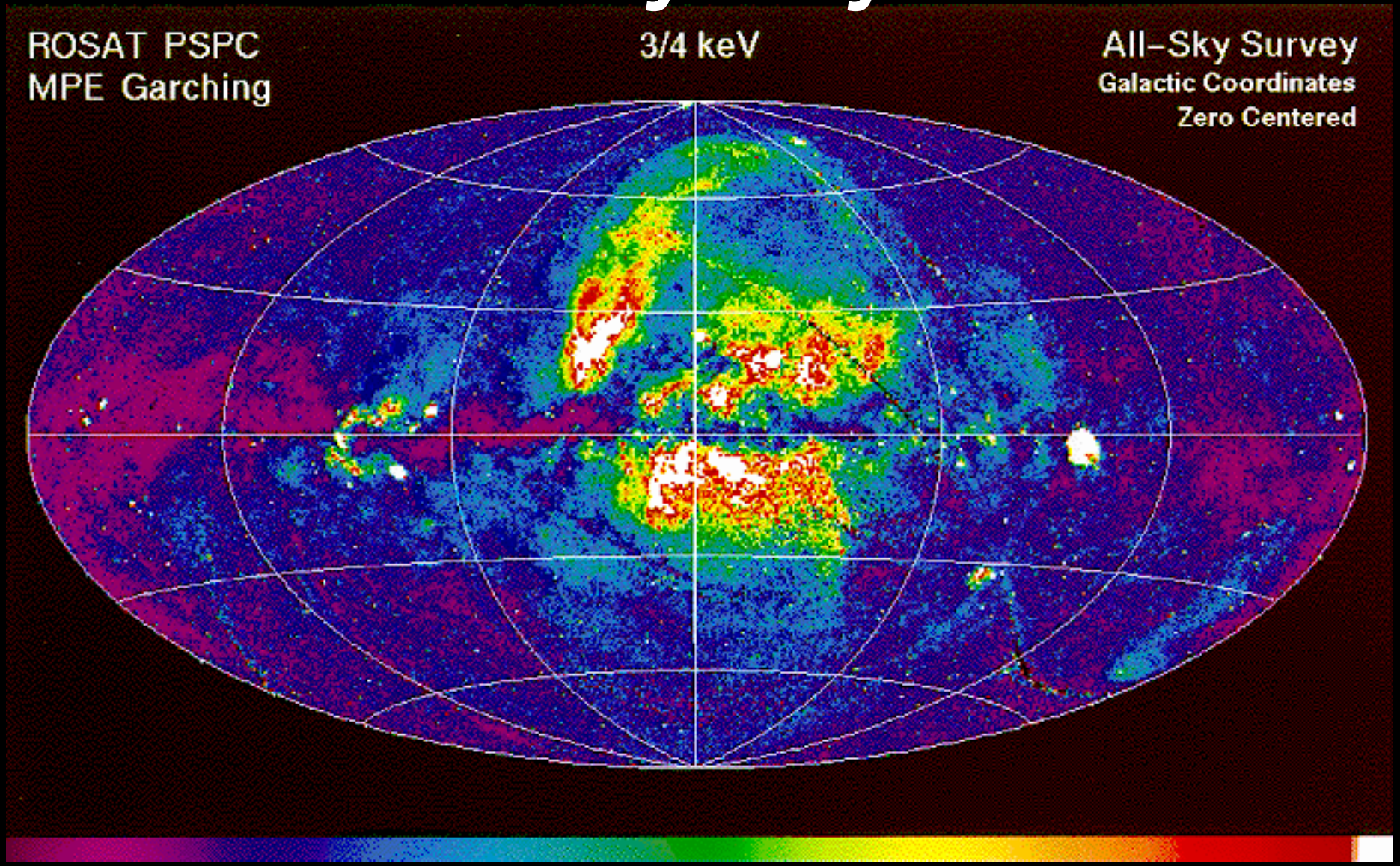
- Key science questions:
  - Mass/baryon/metal and energy budget of galaxies
  - How much mass/baryon/metal and energy are expected v.s. How much are detected
  - How is the CGM connected to star formation?
  - How is the CGM connected to AGN feedback?
  - How the galaxies coevolve with their ecosystem (mergers, LSS)?

Searching for X-ray hot haloes

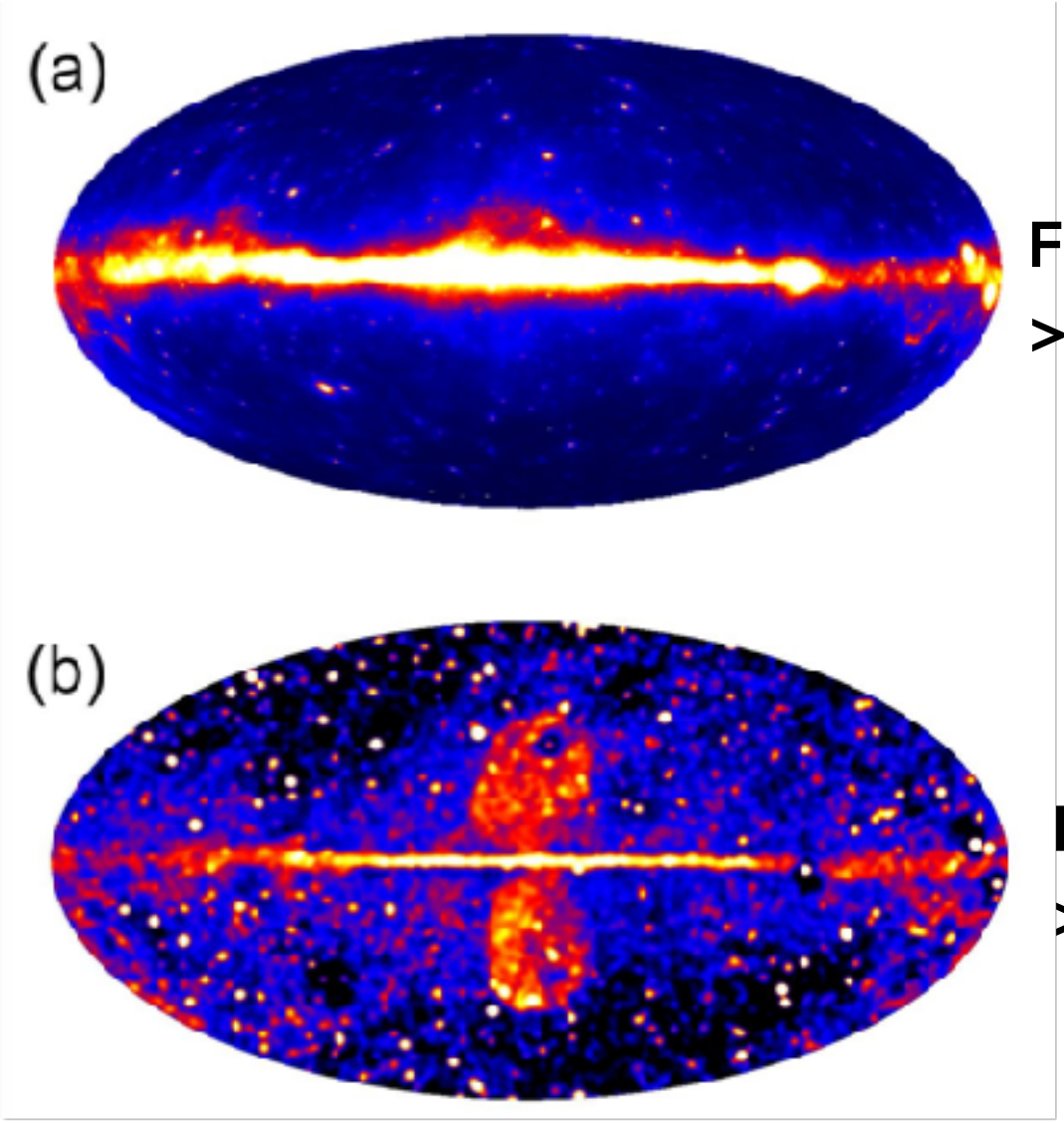


NGC 253; Chandra. Strickland et al. 2002; Strickland et al. 2004

The Milky Way Halo



Fermi Bubbles

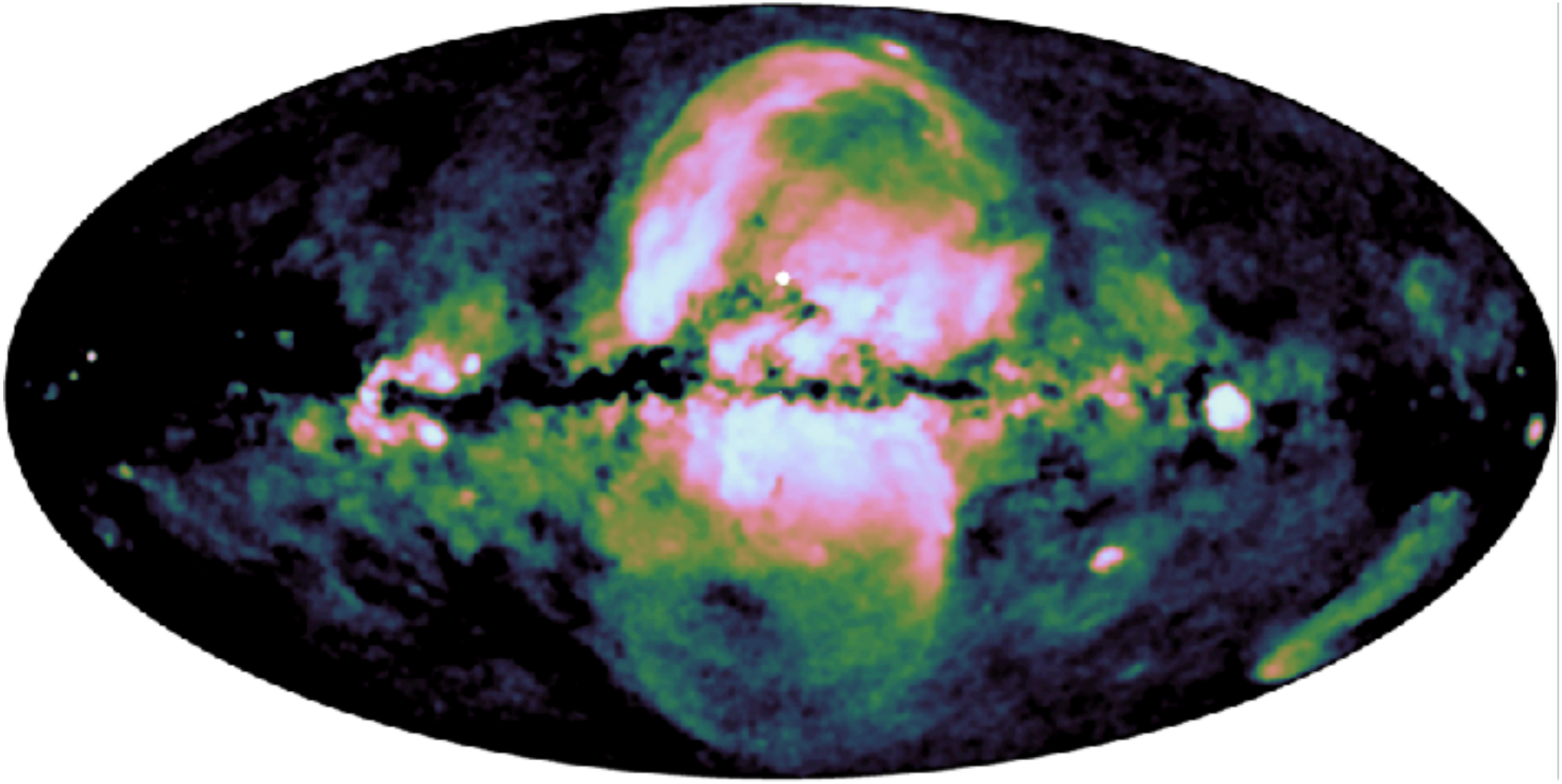


Fermi LAT 8 years map >800MeV

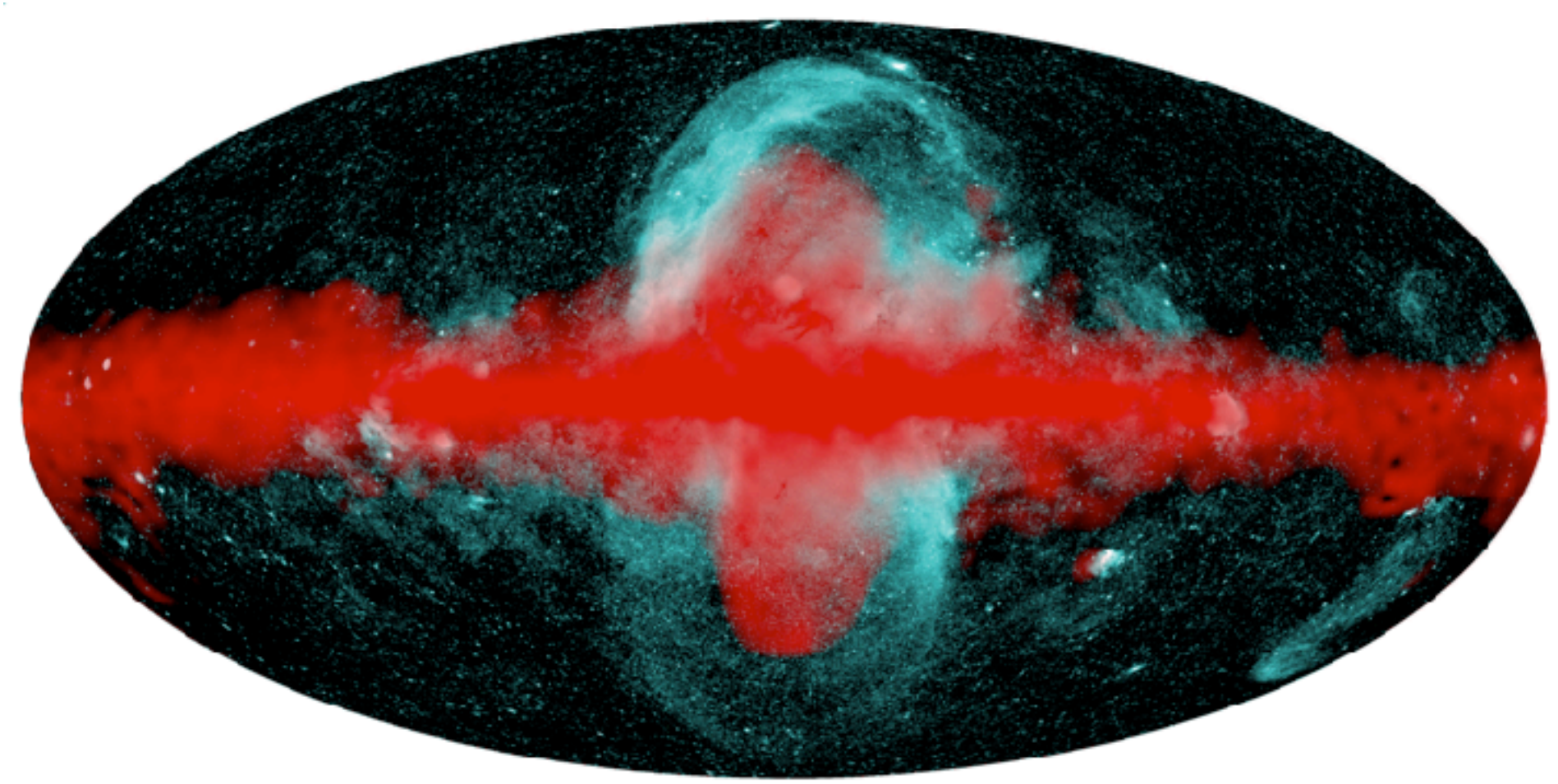
Fermi LAT 'hardness' >3GeV/<3GeV

Kataoka et al. 2018; also: Su et al. 2010; Ackermann et al. 2014

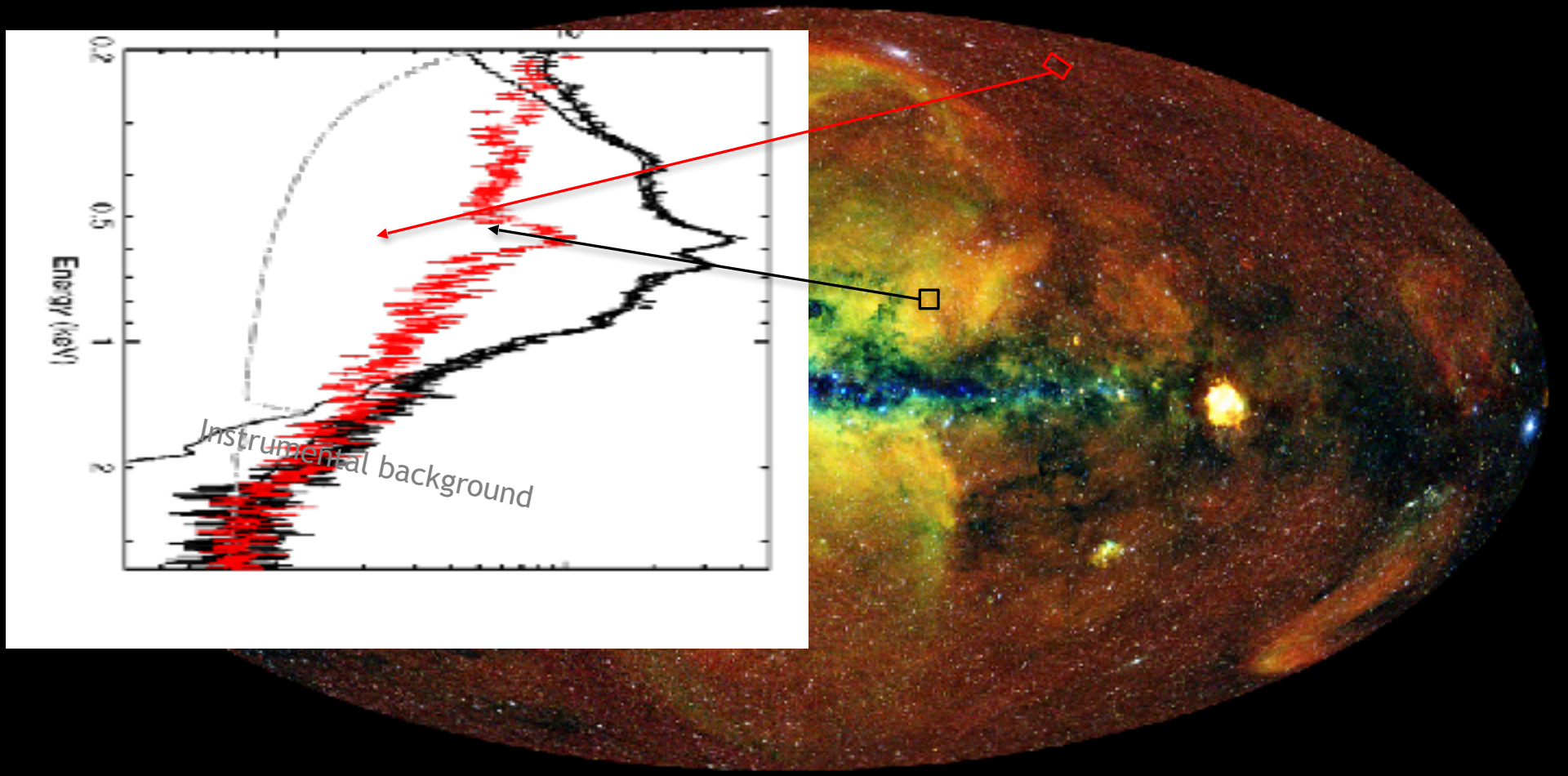
eRASS1, 0.6-1 keV, point sources subtracted



Fermi vs. eRASS1

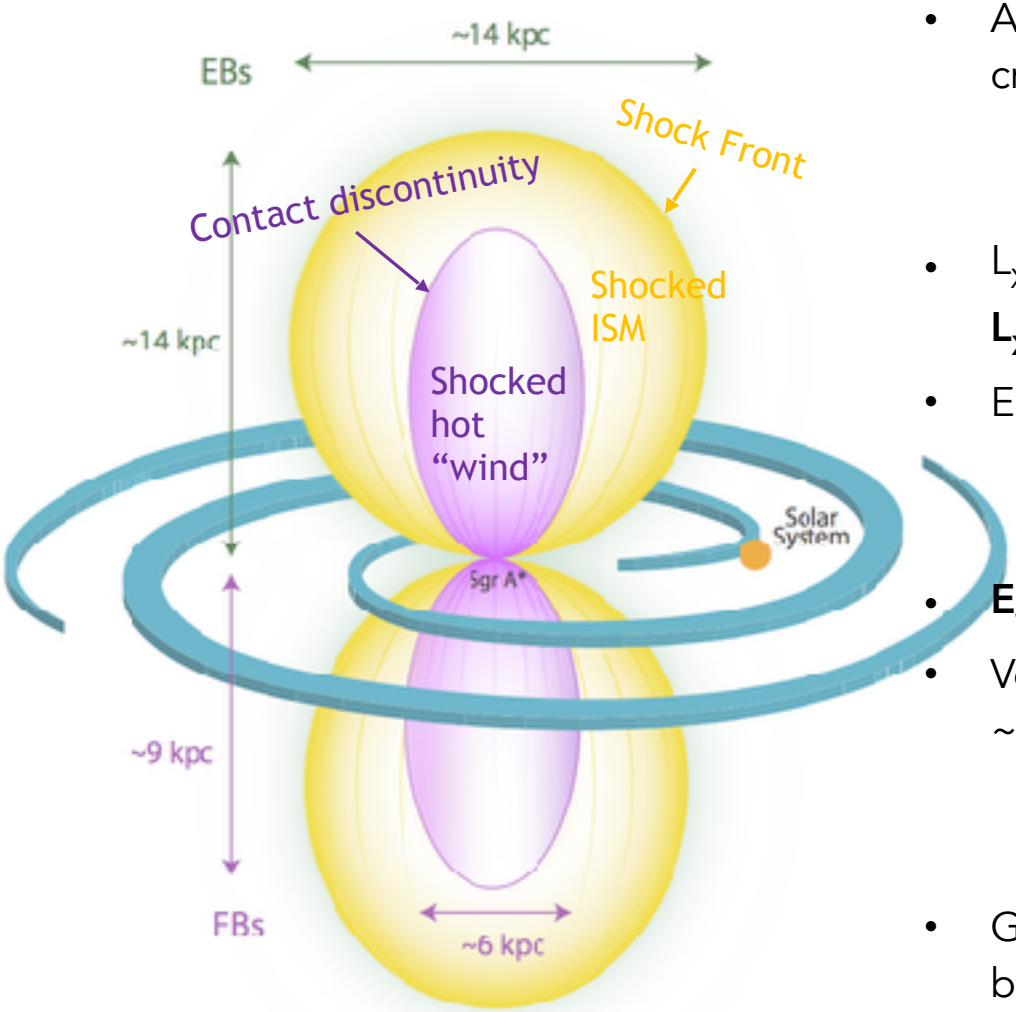


The eROSITA Bubbles; Spectroscopy [work in progress]



G. Ponti, X. Zheng, N. Locatelli, M. Freyberg

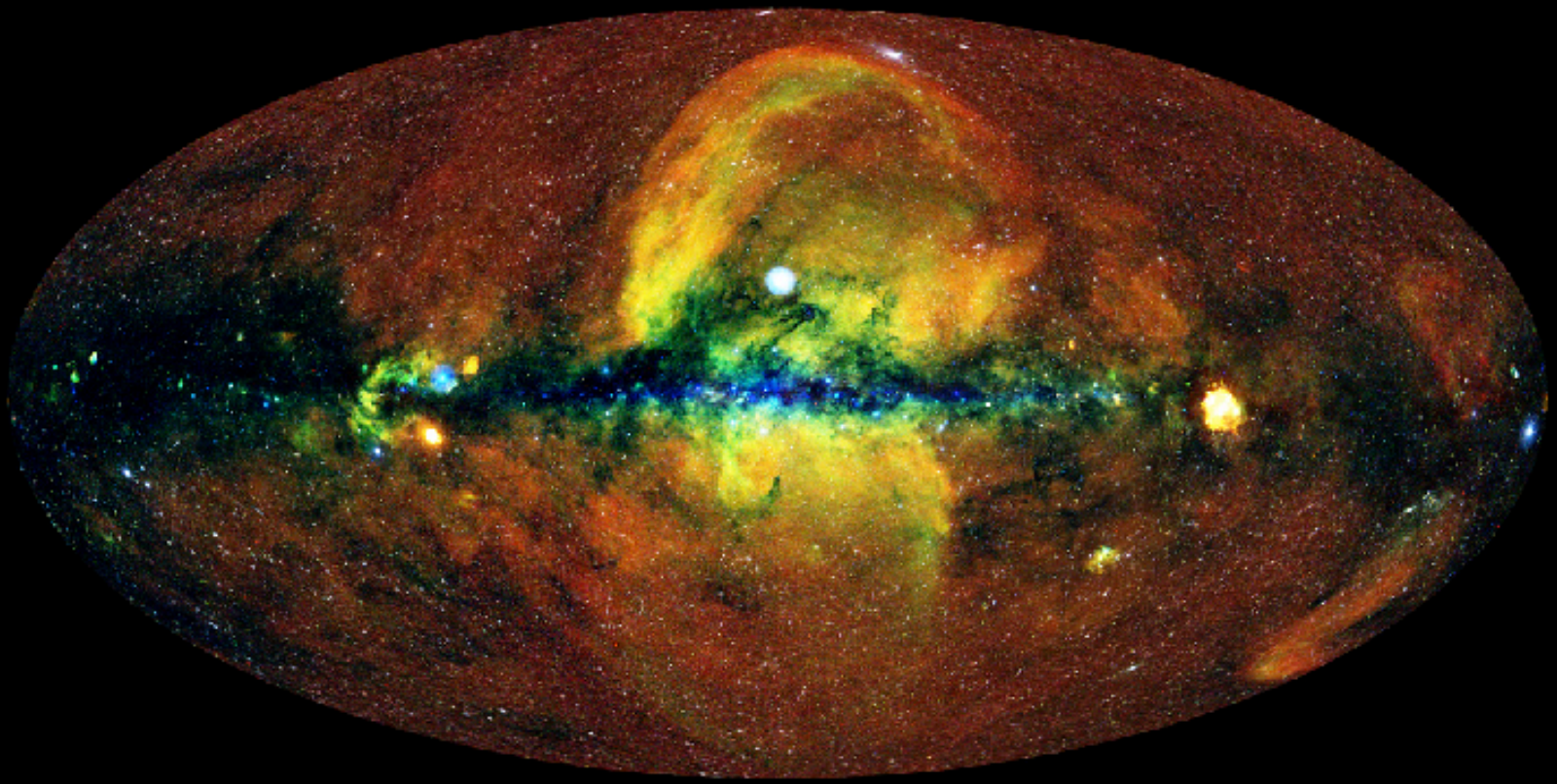
eROSITA Bubbles



- Avg. surface brightness of EBs (2-4)x10^{-15} erg cm^{-2} s^{-1} $arcmin^{-2}$
  - Assume kT=0.3 keV and abundances of 0.2 Solar
- L_X~6.0×10^{38} erg s^{-1} and 4.3×10^{38} erg/s :
  $L_{X,tot}$~10^{39} erg/s
- Energtics:
  - Shock with M~1.5 (from T jump)
  - Compute thermal E of shells
- **E_{tot}~10^{56} erg** (~ 10x Fermi bubbles!)
- Velocity for the M~1.5 shock in a 0.2 keV gas is ~340 km/s
  - **Age~20 Myr**
  - **Energy release rate of ~1-3×10^{41} erg/s**
- Gas Cooling time ~2 x 10^8 years (>> age of bubbles)

Predehl, Sunyaev et al. Nature (2020)

SRG/eROSITA 0.3-2.3 keV - RGB Map

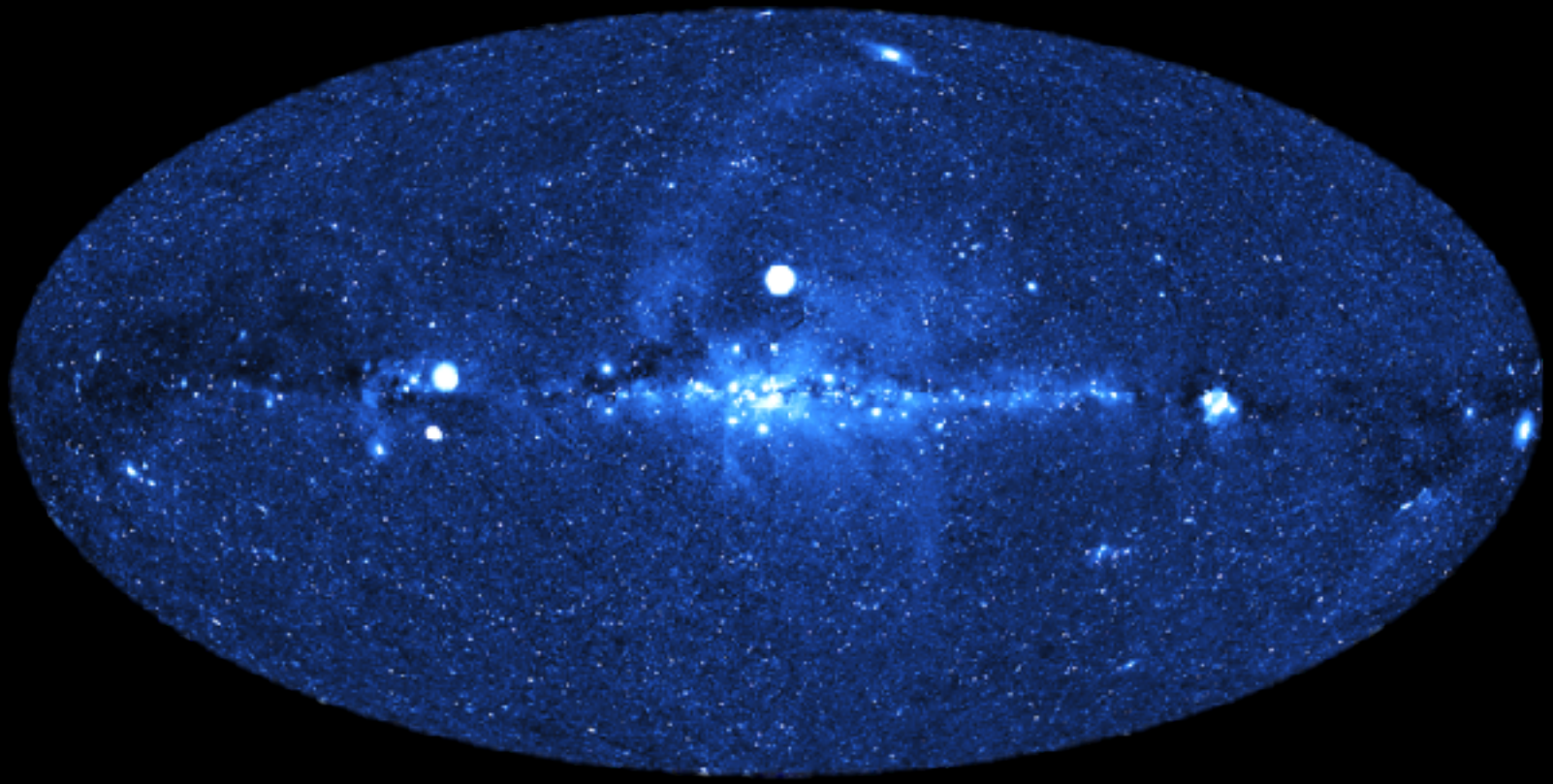


IKI J. Sanders, H. Brunner (MPE), E. Churazov, M. Gilfanov (IKI), and eSASS team MPE

Tracers of Large Scale Structure

SRG/eROSITA

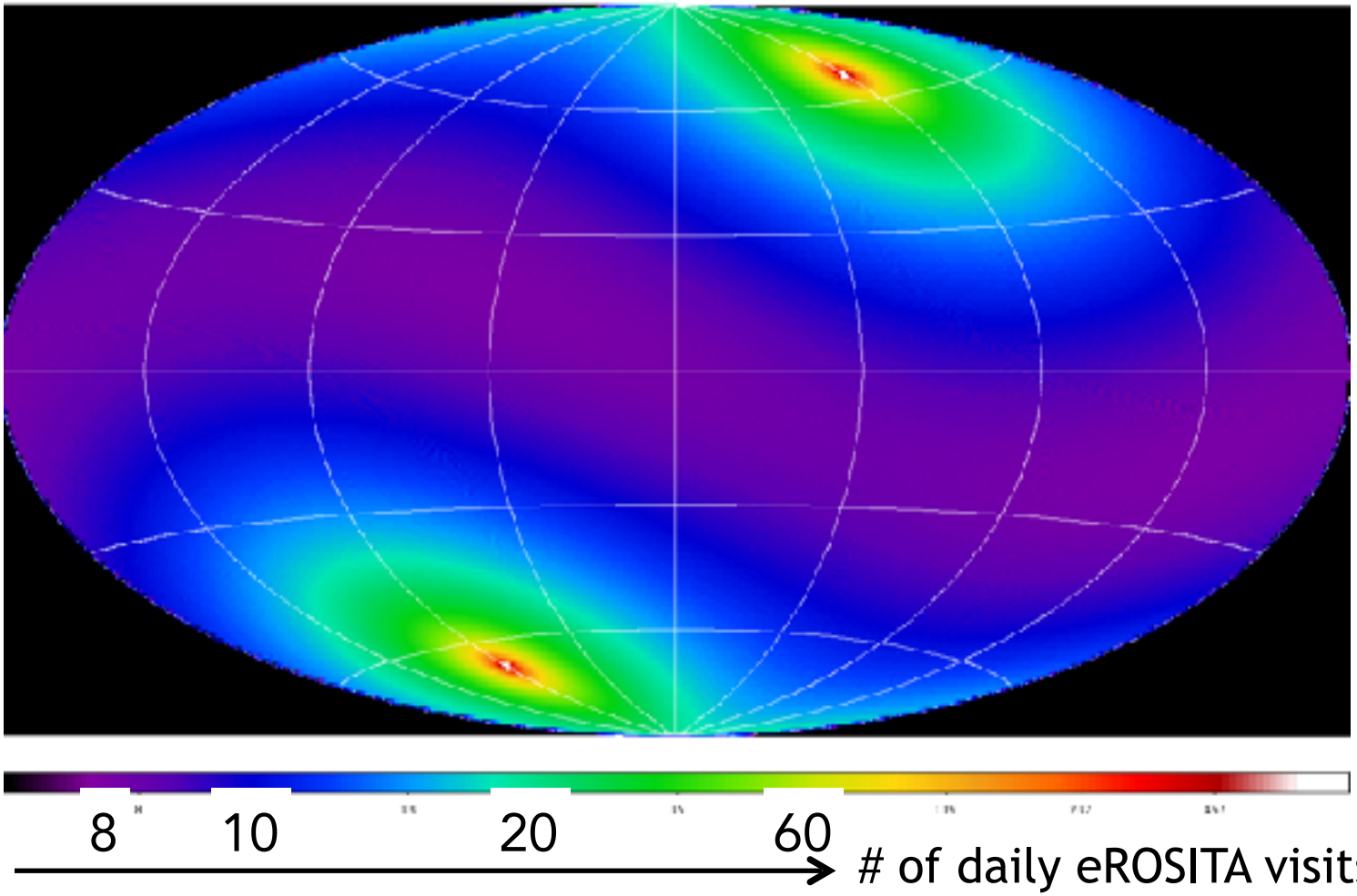
1-2.3 keV



IKI

MPE

eROSITA Cadence Map



1 daily visit ➔ $F_{0.5\text{-}2}$~4×10^{-14} erg/s/cm^2 ➔

$L_X>10^{43}$ at D<1.5 Gpc (z~0.3); $L_X>10^{44}$ at D<4.5 Gpc (z~0.7)

eRASS:8, the legacy

- All clusters more massive than ~$2 \times 10^{14} M_{\odot}$
- >3 Million AGN (<z>~1 and <Lx>~10^{44} ergs/s)
- Compact objects (NS, BH) population of the Milky Way
- Population study of 750k active (young, magnetic) stars
- Nearby star-forming galaxies and galaxy groups
- Dynamical view of the X-ray sky and identify transients and variable sources, including 1000's TDEs
- Serendipity…
- **Data release policy** (German data only; TBC)
  - Early Data Release (EDR): PV/Cal data: June/July 2021
  - All-sky Survey:
    - eRASS:1 (DR1: **Q4 2022**); eRASS:4 (DR2: **Q2 2024**); eRASS:8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Thank you