

# eROSITA on SRG: Mapping the Hot Universe

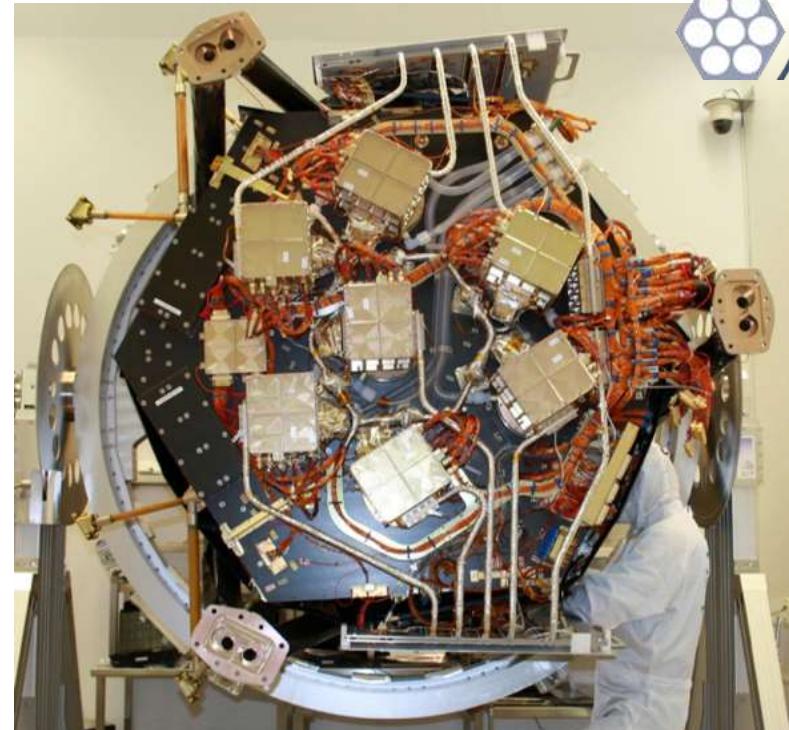
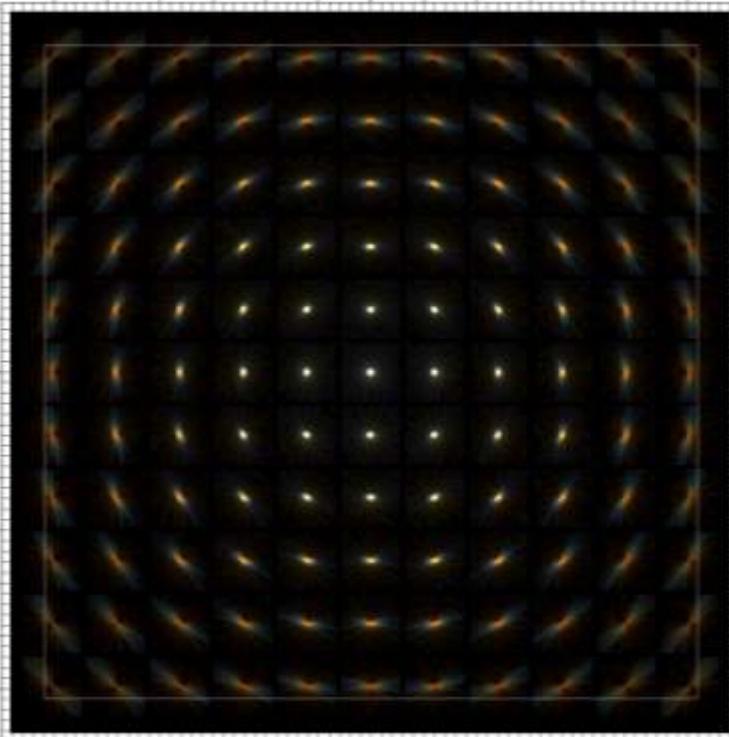
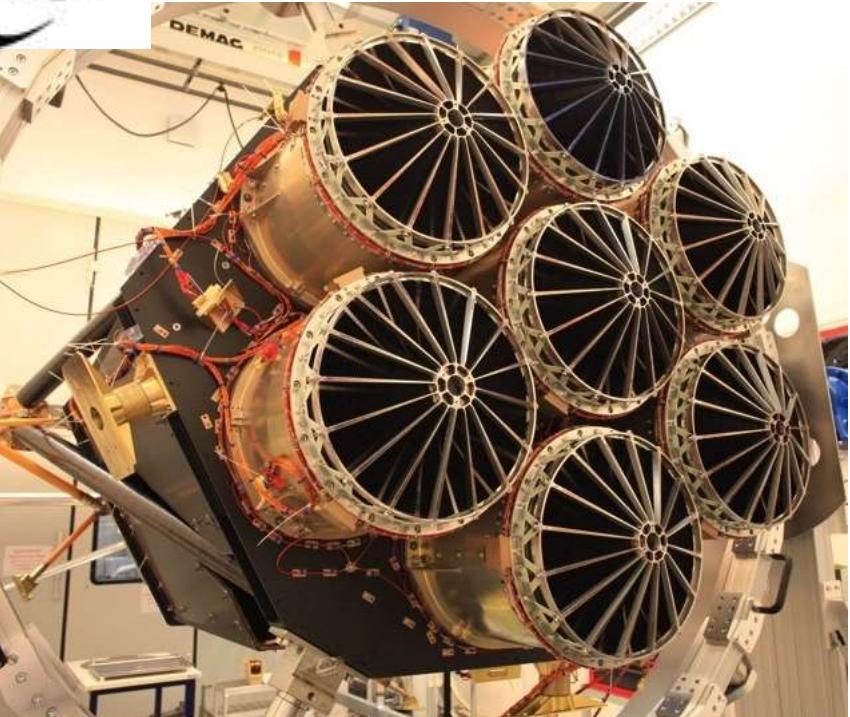
Andrea Merloni (MPE)  
On behalf of the eROSITA-DE team



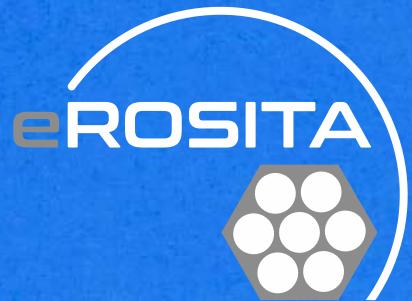
# Outline

- SRG/eROSITA Mission
  - Status, operations, milestones
  - Performance Verification observations
- The all-sky survey: deconstructing the X-ray sky
  - The eROSITA Bubbles
  - The X-ray catalogs
  - Time Domain
- Highlights from the all-sky survey
  - Supernova remnants spectroscopy (M. Mayer)
  - Discovery of a Nova ignition flash (O. König)
  - Quasi Periodic Eruptions (R. Arcodia)

# eROSITA on SRG [Predehl et al. 2021]

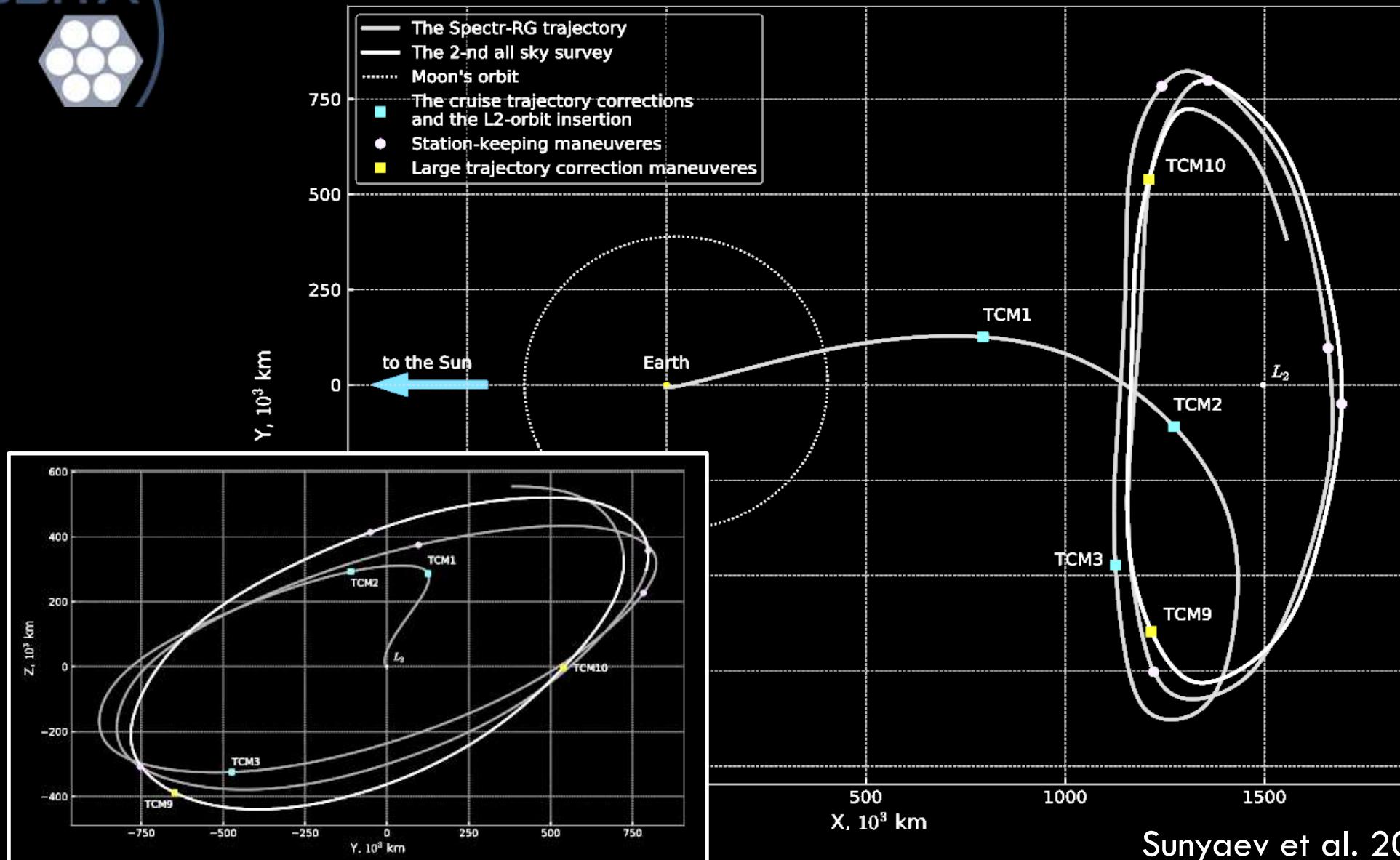


- Large Effective area ( $\sim 1300 \text{ cm}^2$  @1keV, ~XMM-Newton)
- Large Field of view: 1 degree (diameter) -> Grasp  $\sim 5 \times$  XMM
- Half-Energy width (HEW)  $\sim 18''$  (on-axis, point.);  $\sim 30''$  (FoV avg., survey)
  - Positional accuracy:  $\sim 4.5''$  ( $1\sigma$ )
  - X-ray baffle: 92% stray light reduction
- pnCCD with framestore:  $384 \times 384 \times 7 \sim 10^6$  pixels ( $9.4''$ ), no chip gaps, no ‘out of time’ events,
- **Spectral resolution** at all measured energies within specs ( $\sim 80\text{eV}$  @1.5keV)



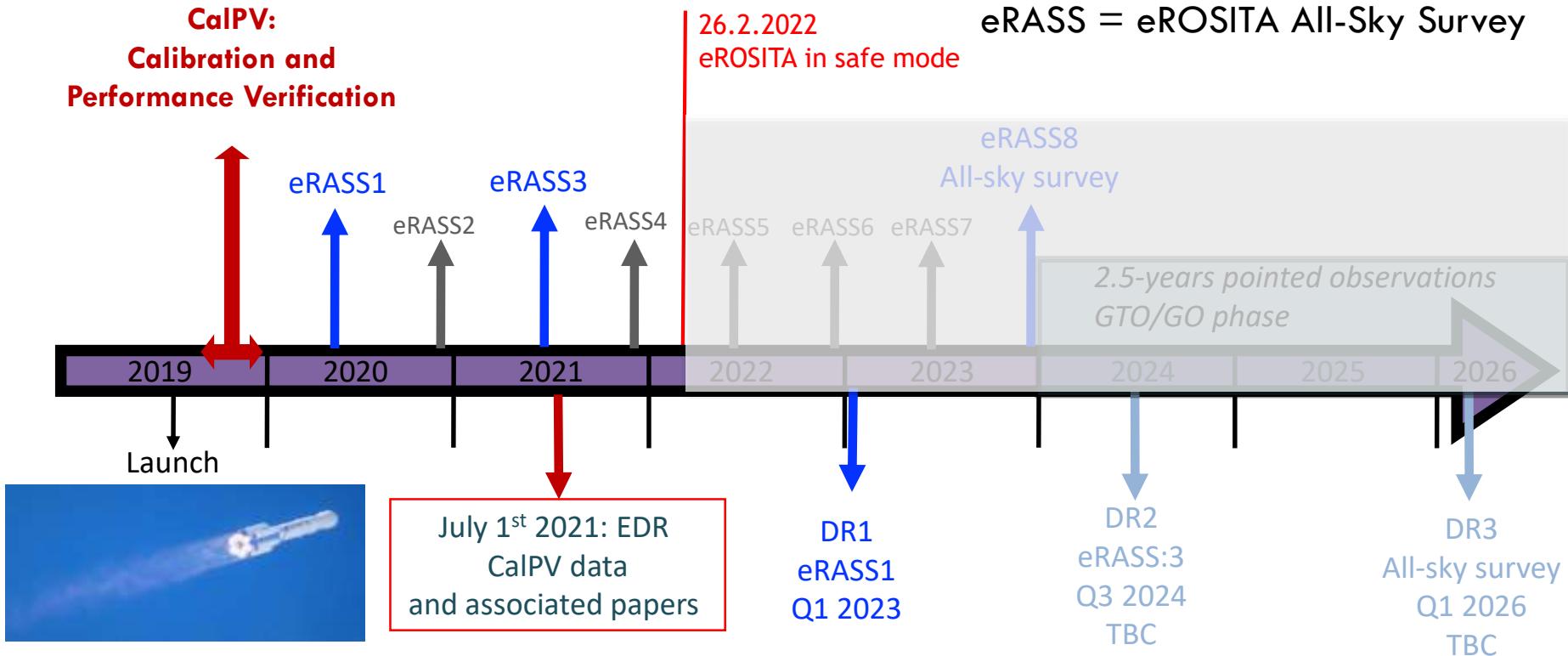


# A large Halo L2 orbit



Sunyaev et al. 2021

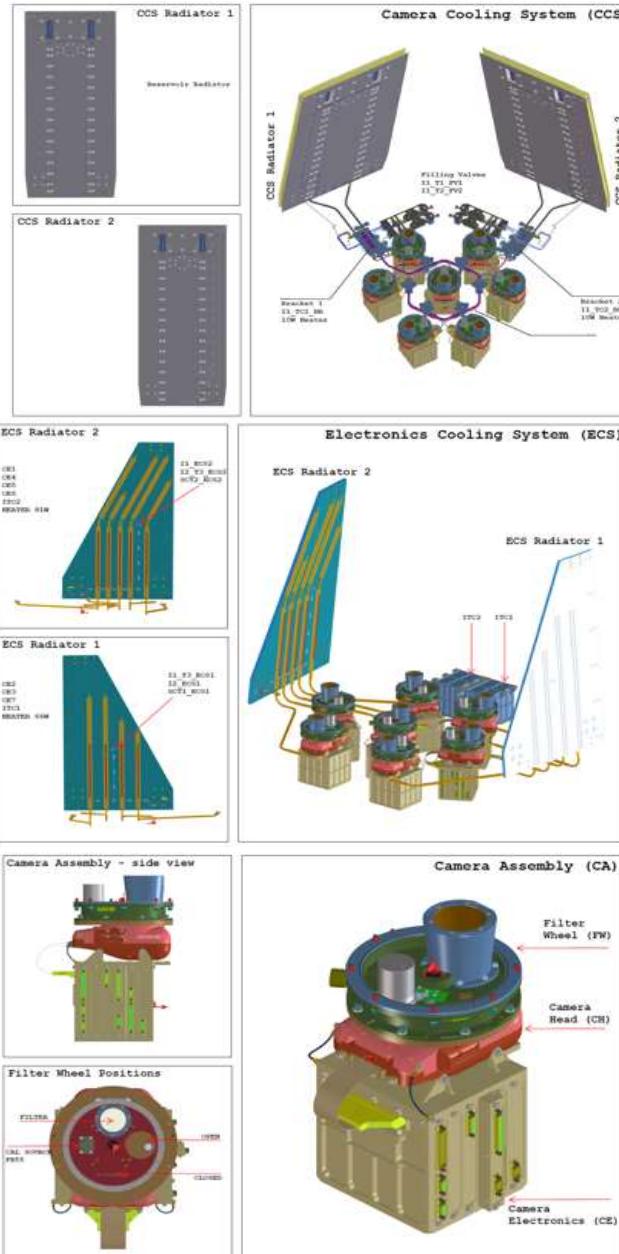
# Programmatics



- Preparation ongoing for DR1: final re-processing of eRASS1 completed last January
- Future DR plan will be revisited depending on the development of the collaboration with IKI

# Instrument Status as of 26.2.2022

- Telescope controller (ITC) operates as expected:
  - Thermal control of Telescope → **OK**
  - Interface & control to Camera Electronics → **OK**
  - Interface to S/C and Mass memory → **OK**
- Mirror Thermal Control:
  - Maintains mirrors at  $\sim 20^\circ\text{C} \pm 1^\circ\text{C}$  as required → **OK**
- Electronics Thermal Control:
  - Electronics at a temperature of  $< -10^\circ\text{C}$ . → **OK**
- CCD Camera Cooling:
  - Camera temperature at  $-85^\circ \rightarrow -82^\circ \pm 0.1^\circ\text{C}$  → **OK**
- Camera Assemblies (x7)
  - Filter Wheels are functional, filter is intact → **OK**
  - Camera Electronics are healthy and functional → **OK**
  - CCD Cameras perform as in ground testing → **OK**
  - **Four likely micro-meteoroids impacts (TM4, TM5, TM7, TM2), affecting (~1000, 8, 38, 4) pixels**
  - **Light leak affects spectroscopic capabilities of 2 cameras (TM5 and TM7)**





# eROSITA by Numbers



As of 3.5.2022	
Days in Space	1066
Days in full operating mode	870
eRASS1 Survey percentage	100% (187 days)
eRASS2 Survey percentage	100% (185 days)
eRASS3 Survey percentage	100% (186 days)
eRASS4 Survey percentage	100% (188 days)
eRASS5 Survey percentage	41% (77 days)
Data downloaded	~410 GB
Avg. camera availability [eRASS2,3]	97%
Avg. total outage time [eRASS:1-4]	6.3%
Avg. commands rate	75/day
Average data rate	450 MB/day
Maximum power consumption	340W < P < 360W

Courtesy of Diogo Coutinho, Ia Stewart, Miriam Ramos-Ceja and MPE eROSITA Operations Team

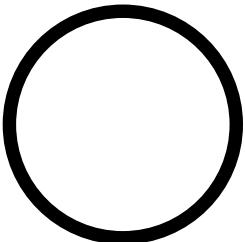
# eROSITA's advantage:

## large Field of View and Grasp

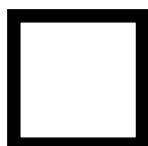
Moon diameter  
30 arcmin



XMM-Newton  
Field of view ~ 30 arcmin



Chandra  
Field of view ~ 17 arcmin

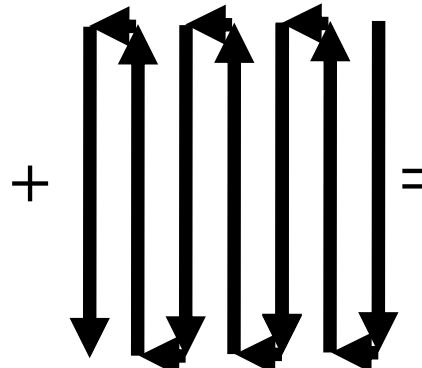
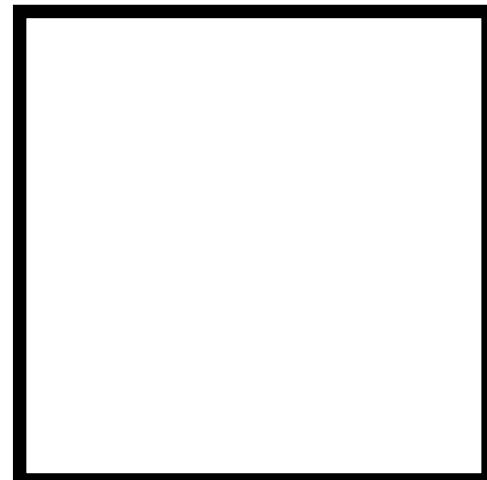


Grasp (= survey speed)

- 5 x XMM-Newton
- 100 x Chandra (today)

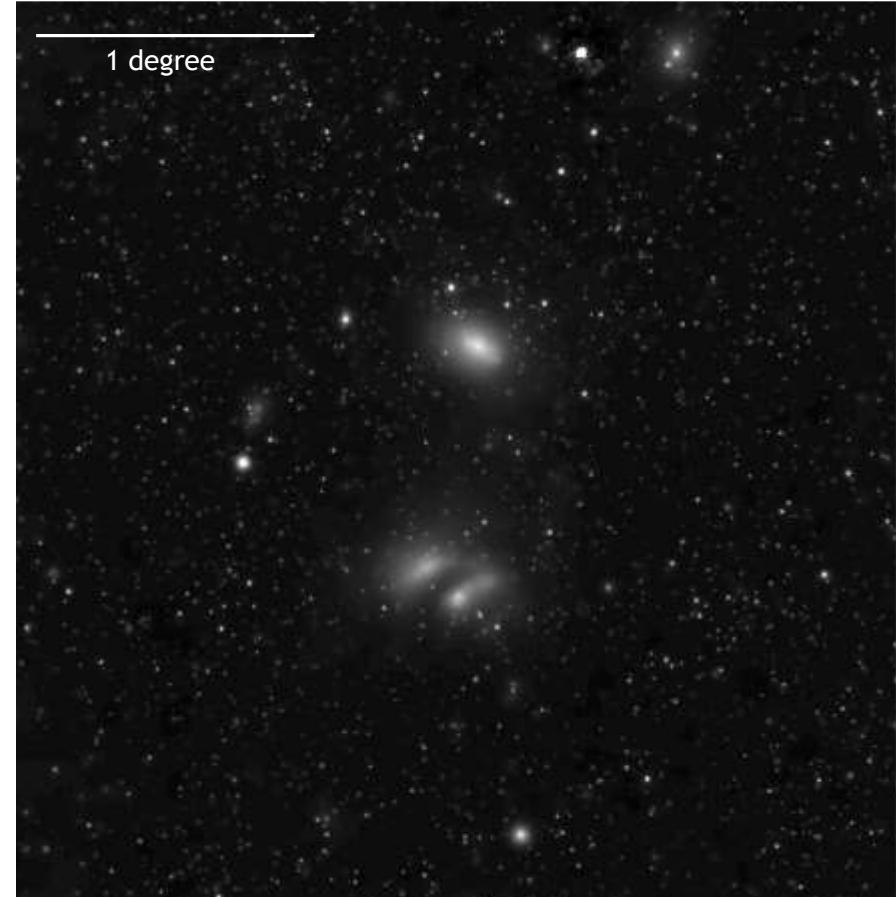
eROSITA

Field of view ~ 62 arcmin



**3 Observing modes:**

continuous scan (survey), field scan, pointing

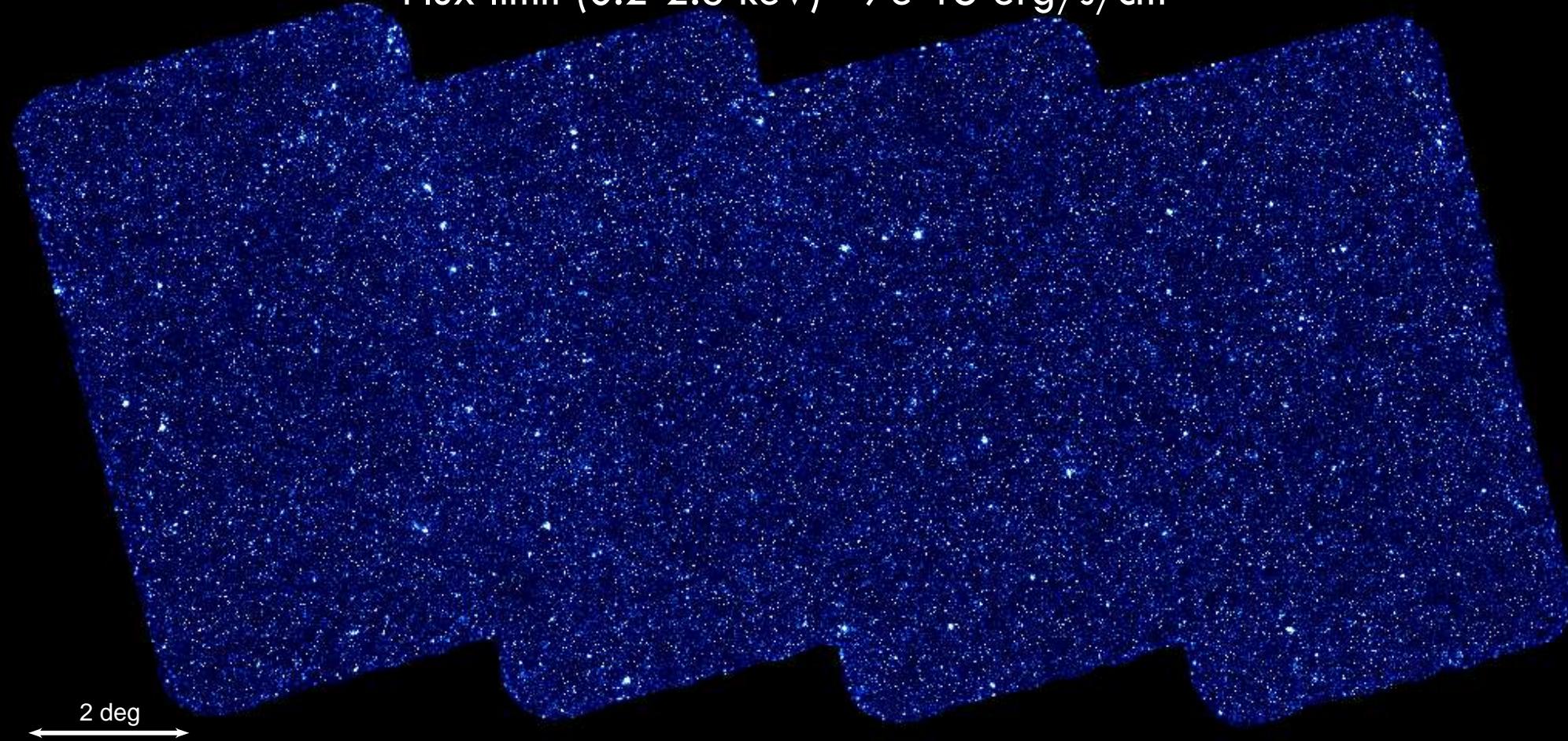


SRG/eROSITA 0.2-2 keV image of  
A3391/3395  
(Reiprich et al. 2021)

# eFEDS: a preview survey

140 deg<sup>2</sup>; ~2.5ks exposure; ~27k X-ray sources; ~12k spec-z (SDSS-IV,V)

Flux limit (0.2-2.3 keV) ~7e-15 erg/s/cm<sup>2</sup>



Credit: H. Brunner, M. Ramos-Ceja

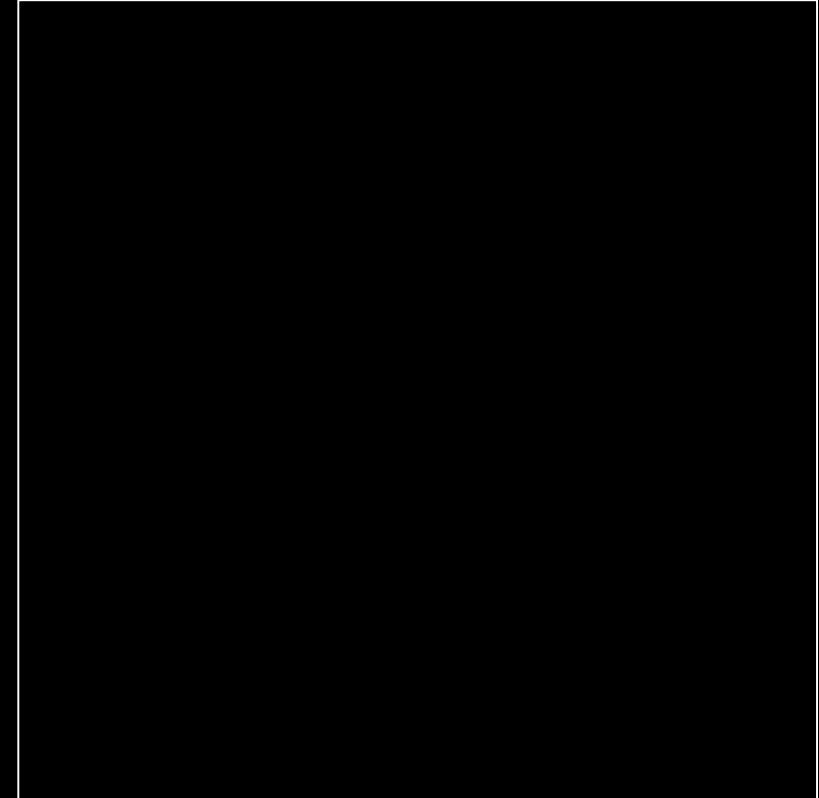
Exposure corrected image in the 0.5–2.0 keV band

Merloni, X-ray 60, 06/2022

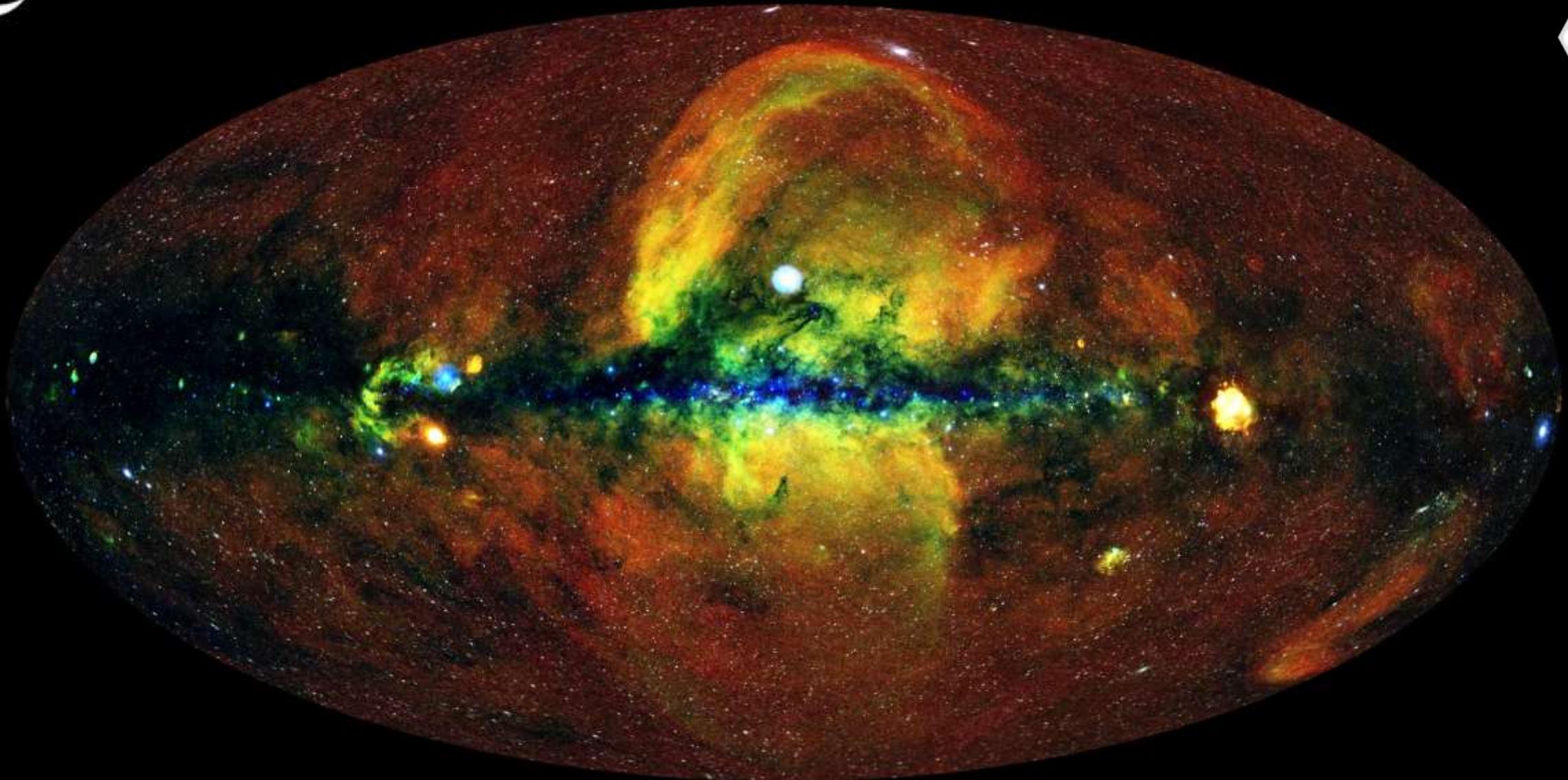
# eFEDS results

- Catalogue Papers
  - H. Brunner et al.: “eFEDS: The X-ray catalogue”
  - M. Salvato et al. “eFEDS: identification and characterization of the ctps. to the point-like sources”
  - T. Liu et al. “eFEDS: The AGN Catalogue and its X-ray Spectral Properties”
  - A. Liu et al. “eFEDS: The catalogue of galaxy clusters and groups”
  - E. Bulbul et al. “eFEDS: Galaxy clusters and groups in disguise”
  - S. Schneider et al. “eFEDS: The stellar counterparts of eROSITA sources identified by machine learning and Bayesian algorithms ”
  - K. Nandra et al.: “eFEDS:: The hard X-ray selected sample”, in prep.
- Clusters weak lensing mass calibration (Chiu et al.)
- Comparison with shear-selected cluster sample (Ramos-Ceja et al.)
- Constrain on evolution of clusters scaling relations (Behar et al.)
- Cluster morphological analysis: no bimodality (Ghirardini et al.)
- Radio AGN feedback in groups and clusters (Pasini et al.)
- Obscured QSOs and AGN feedback (Brusa et al., Toba et al.)
- Variable sources (Boller et al.)
- Study of nearby Galaxies (Vulic et al.)

# SRG: all-sky survey



**4 years: 8 all sky surveys (eRASS1-8)**

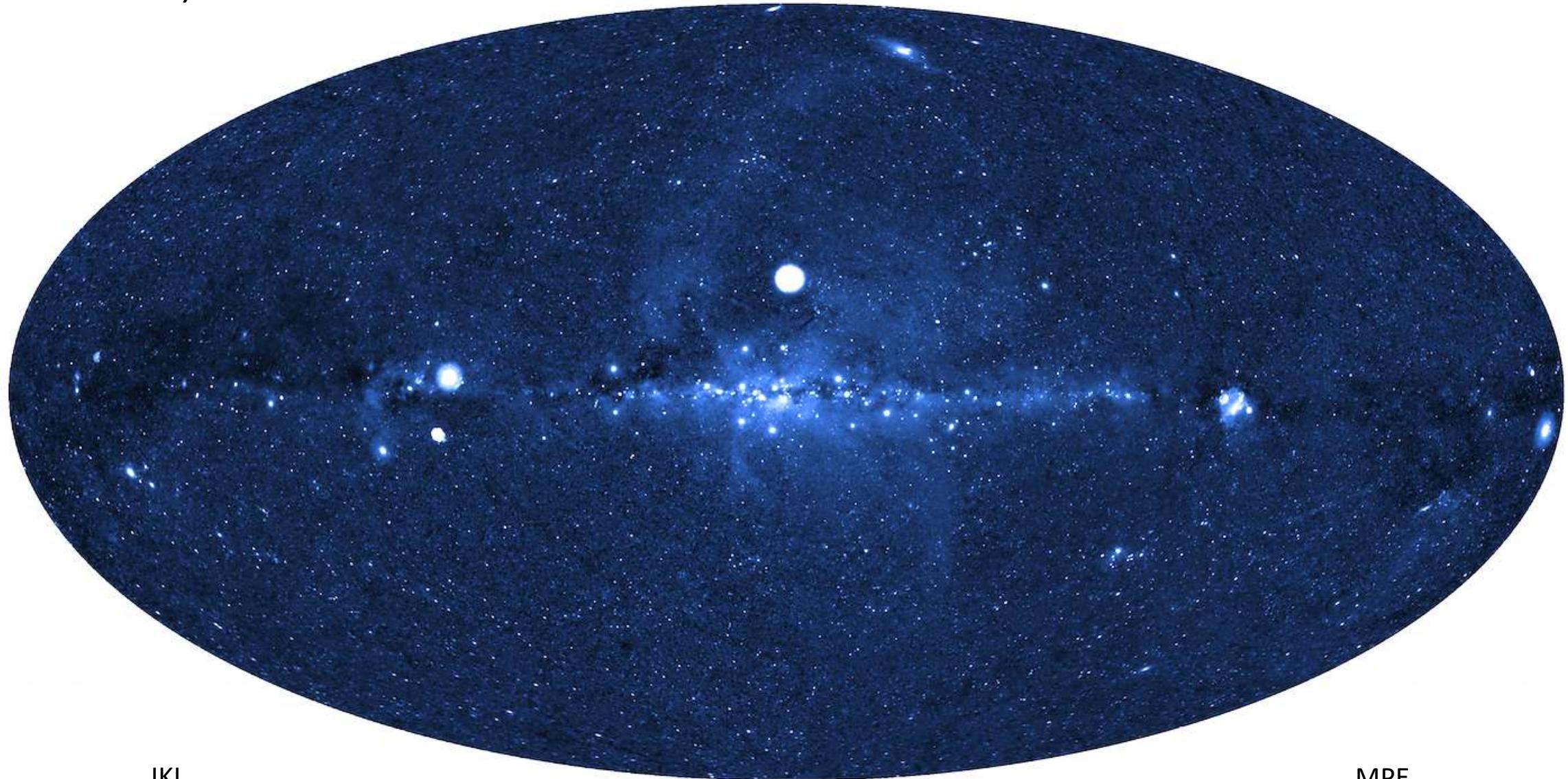


IKI

MPE

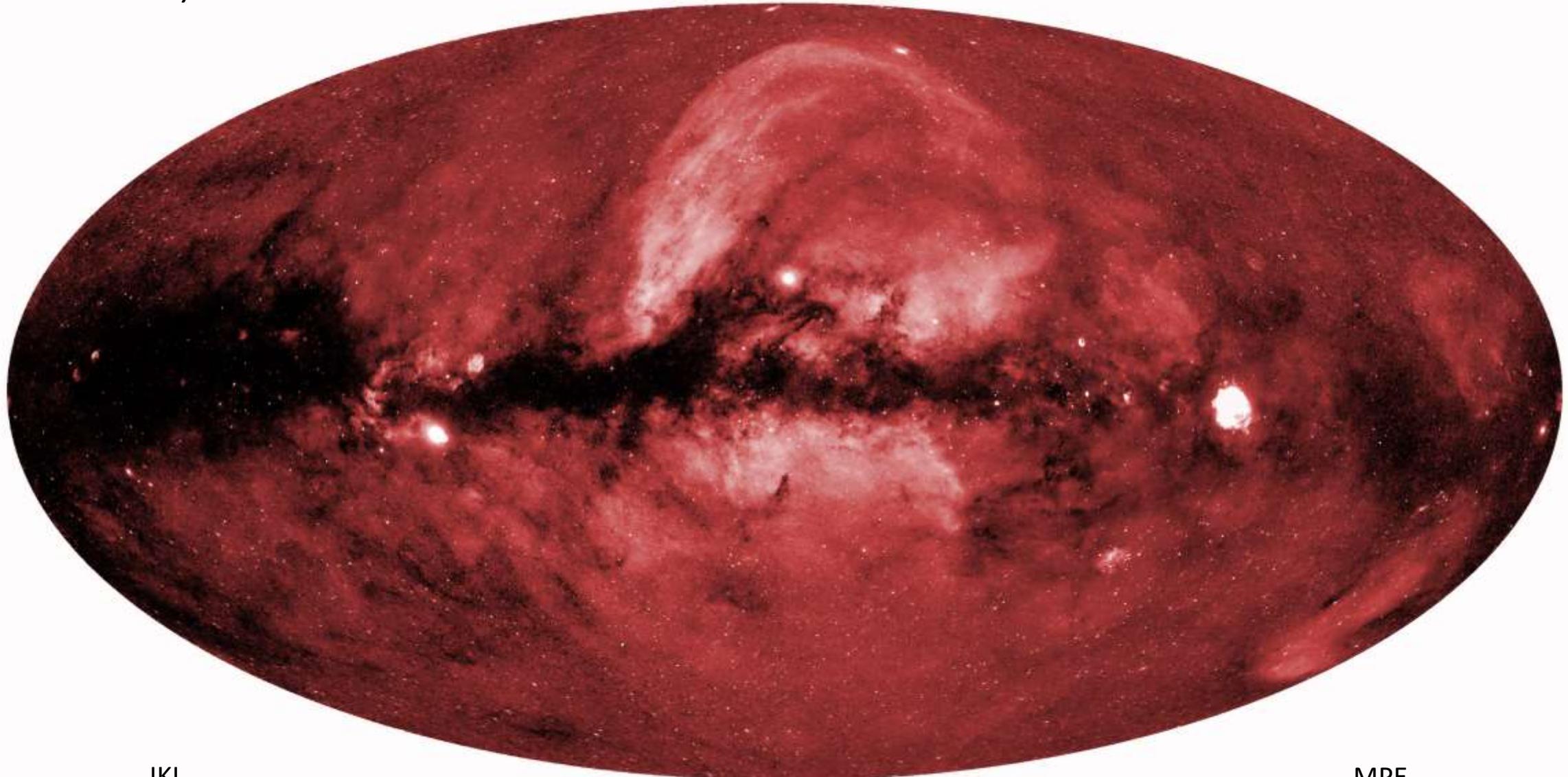
*SRG/eROSITA*

*1.0-2.3 keV*



*SRG/eROSITA*

*0.3-0.6 keV*

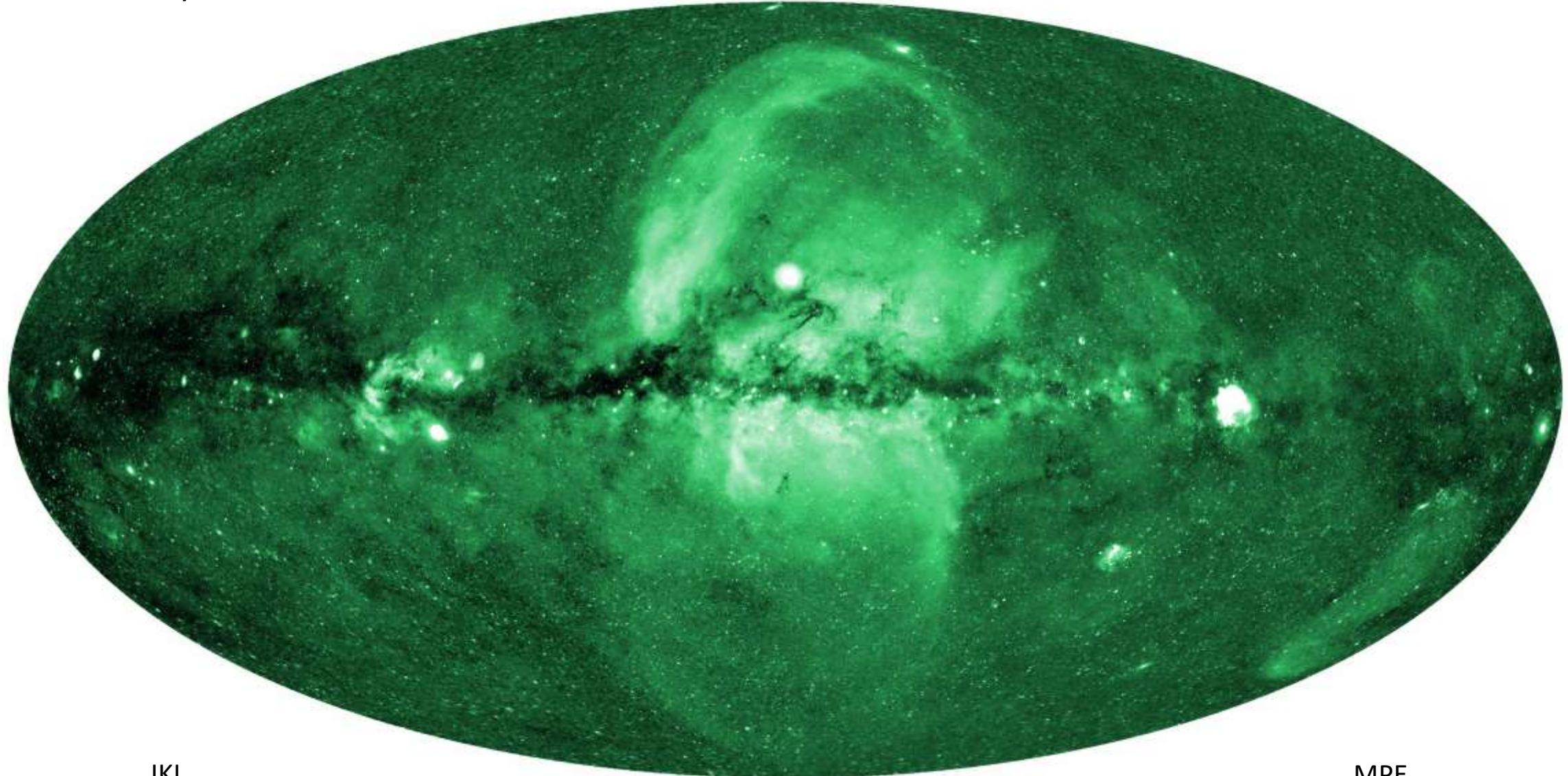


IKI

MPE

*SRG/eROSITA*

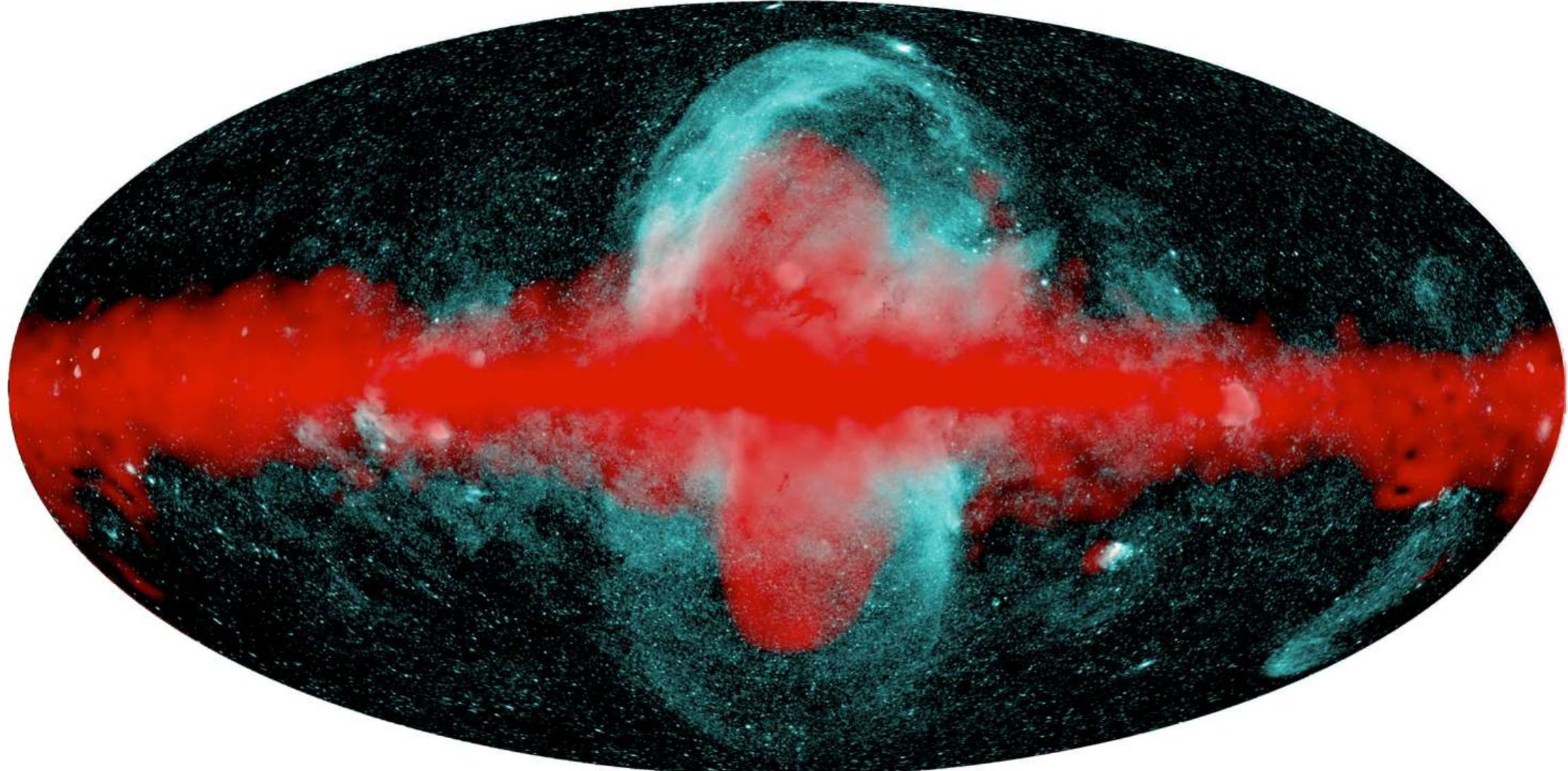
*0.6-1.0 keV*



IKI

MPE

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

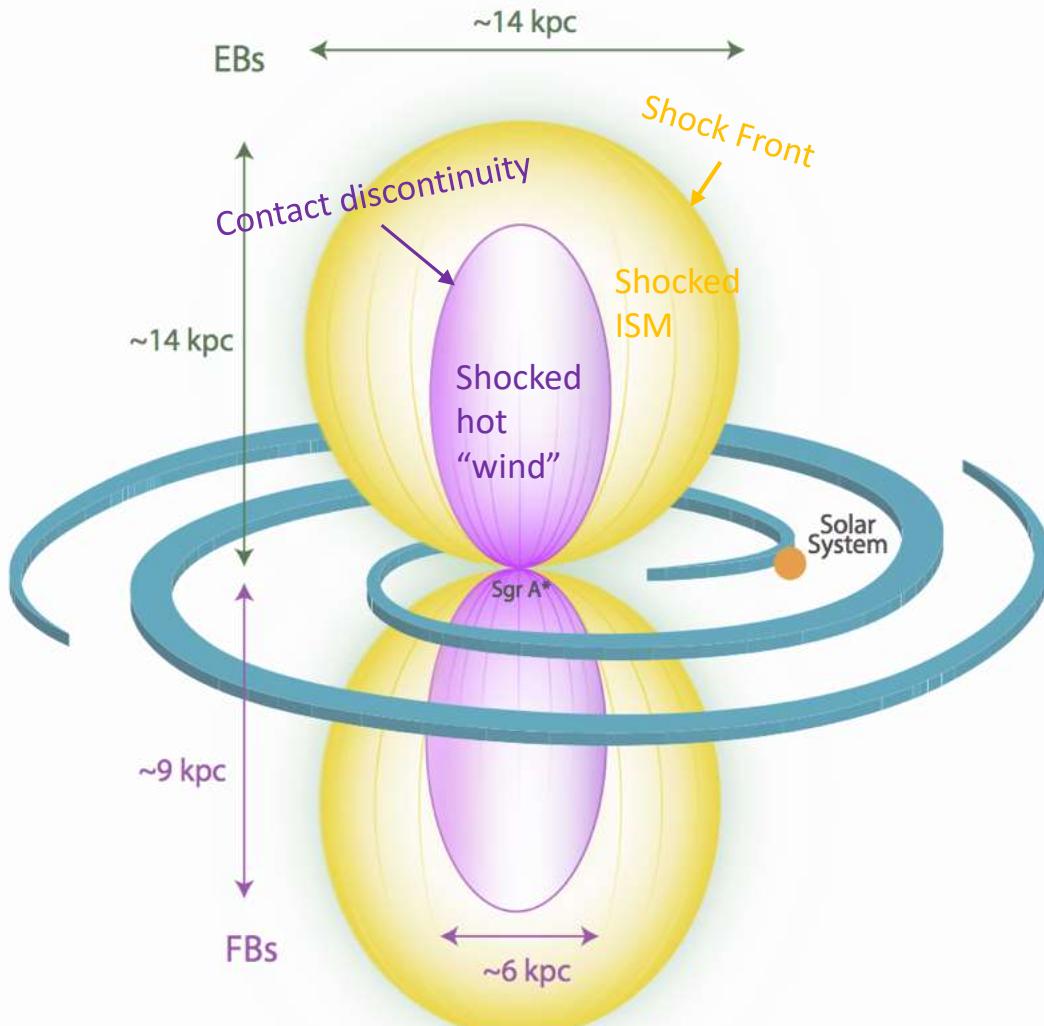


Credit: Khabibullin, Selig (MPA)

Merloni, X-ray 60, 06/2022

18

# The eROSITA Bubbles



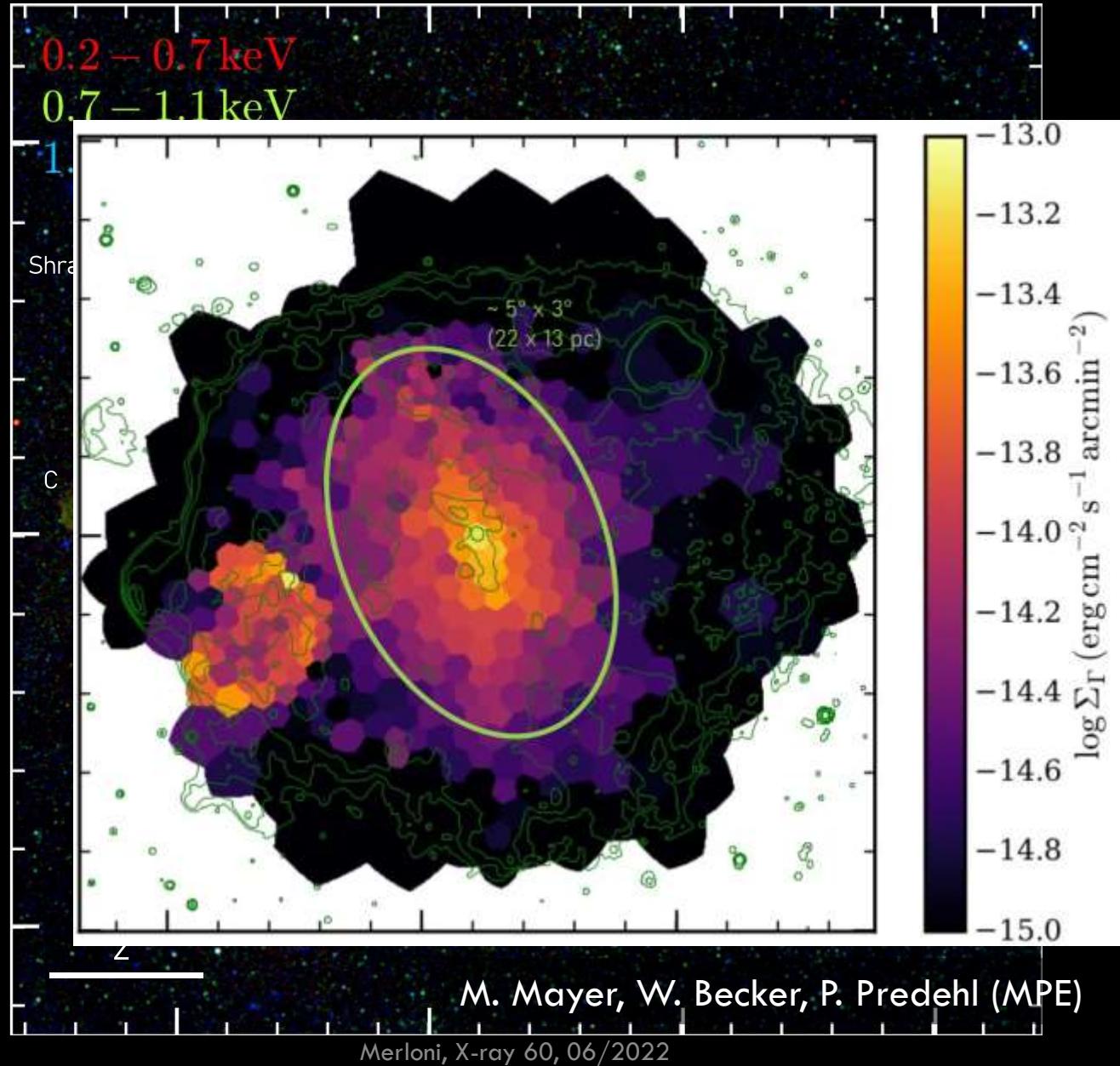
- $L_{X,\text{tot}} \sim 10^{39} \text{ erg/s}$
- Energetics:
  - Assume  $kT=0.3 \text{ keV}$  and abundances of 0.2 Solar
  - Shock with  $M \sim 1.5$  (from T jump)
- $E_{\text{tot}} \sim 10^{56} \text{ erg}$  ( $\sim 10x$  Fermi bubbles!)
  - Age  $\sim 20 \text{ Myr}$
  - Energy release rate of  $\sim 1-3 \times 10^{41} \text{ erg/s}$
- Gas Cooling time  $\sim 2 \times 10^8 \text{ years}$  ( $>>$  age of bubbles)

Predehl, Sunyaev et al. Nature (2020)

**POSTERS from Predehl, Strong**

# Vela and friends

Non-thermal  
Component:  
Large-scale  
particle  
acceleration?



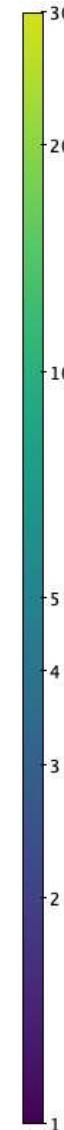
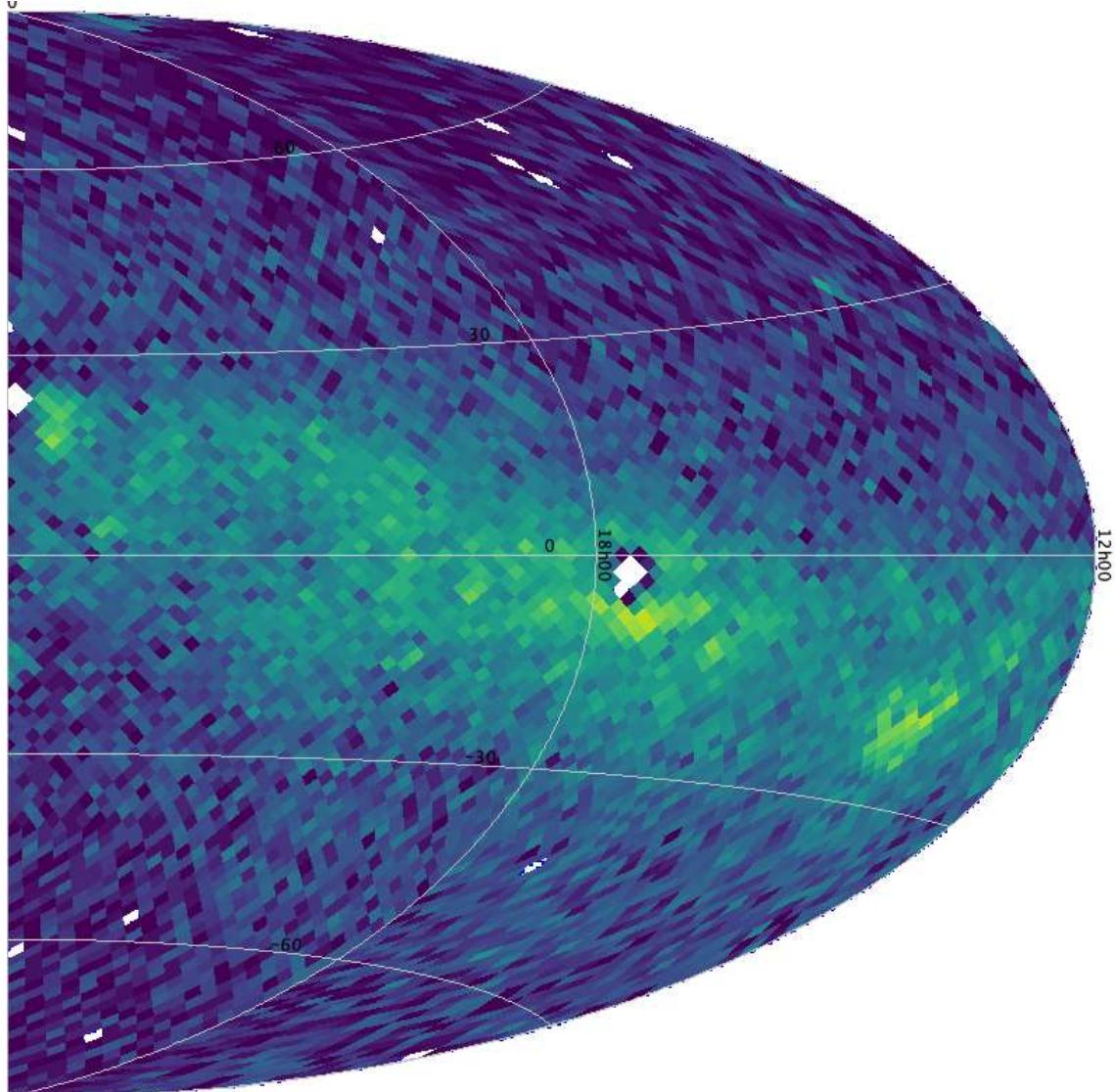
# eRASS1 point source half-sky catalog

S/N limit → Purity

	Detection Likelihood>5	Detection Likelihood>10
ALL	11237k	423k
Fraction of spurious (est.)	~25%	~1%
Bright ( $F_{0.2-2.3\text{keV}} > 4.5\text{e-}14$ )	473k	302k
Bright, MS-stellar	74k	64k
Bright, non-stellar	399k	238k

Highly pure and complete flux-limited sample

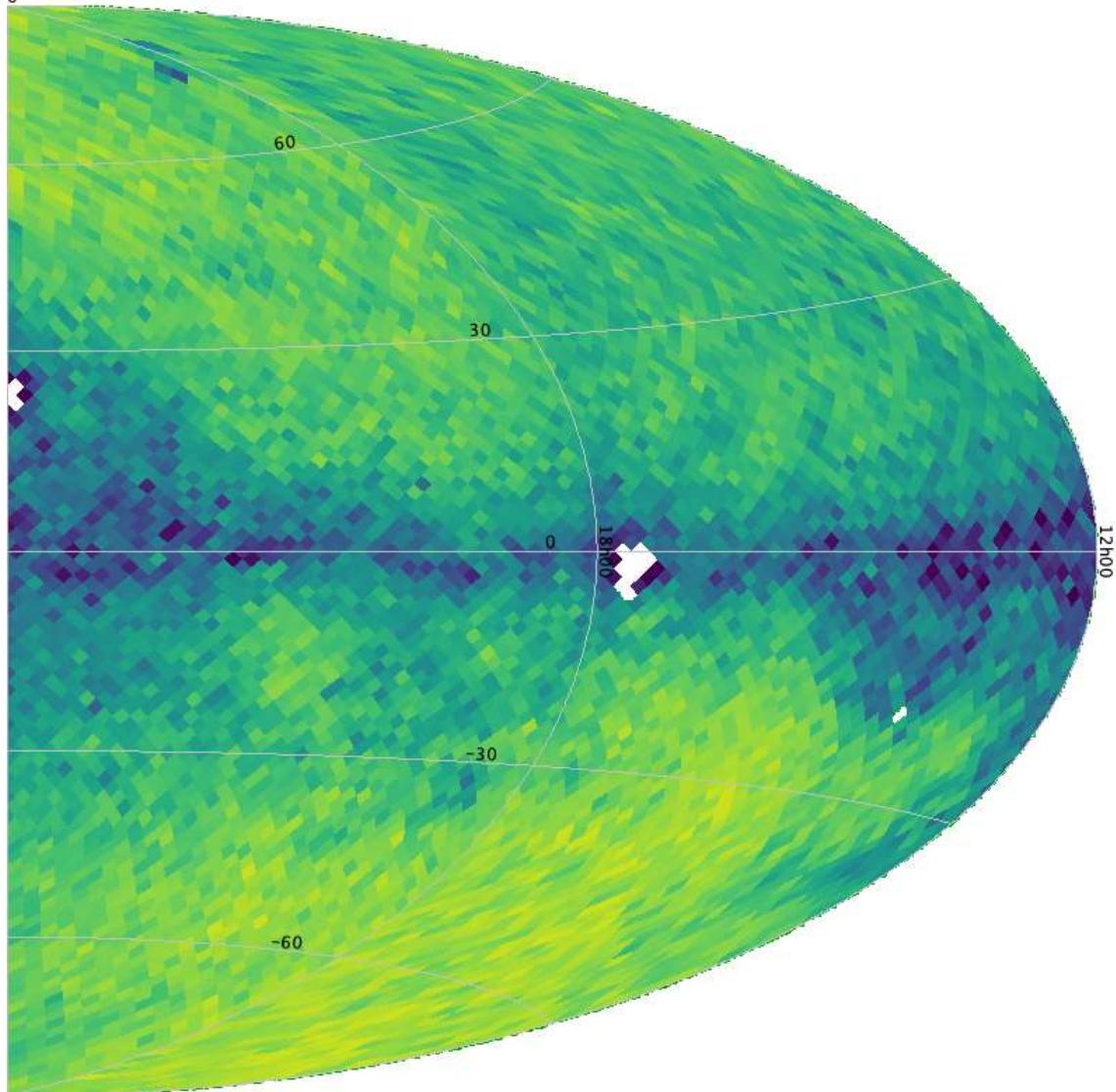
# eRASS1 “clean” point source half-sky catalog



## Stellar source density

- Highly pure and complete flux-limited sample
- 64k stellar sources
- Source density closely traces nearby (<500pc) star forming regions (Gould Belt)
- >10% of all known planet hosting stars! (Katja Poppenhäger, AIP)

# eRASS1 “clean” point source half-sky catalog

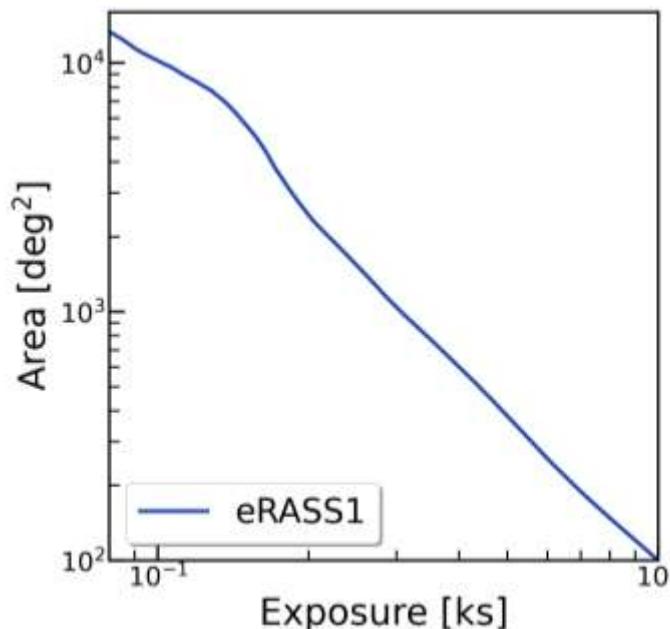
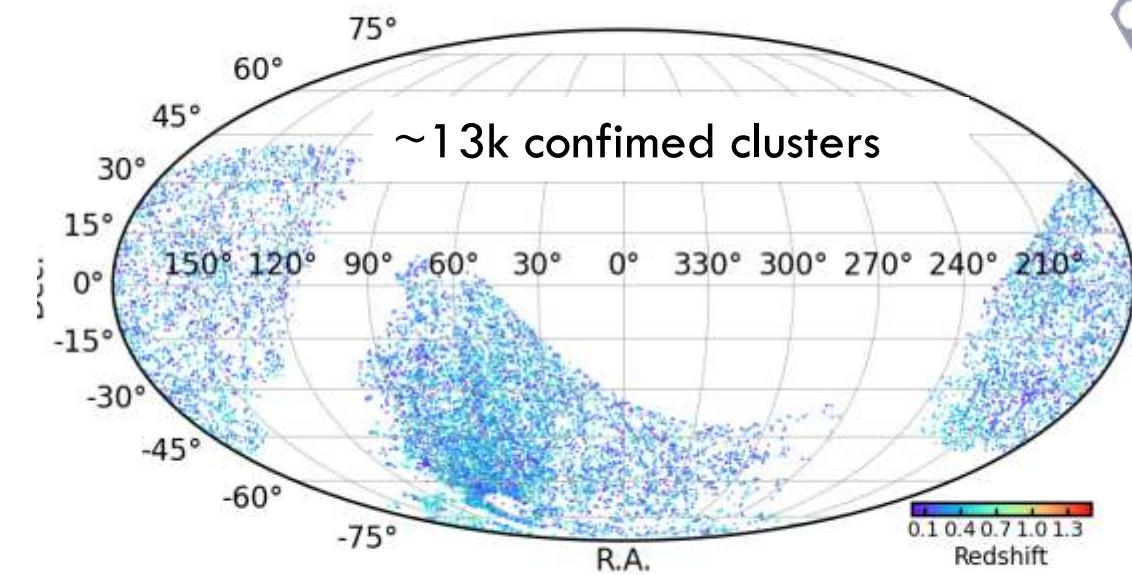
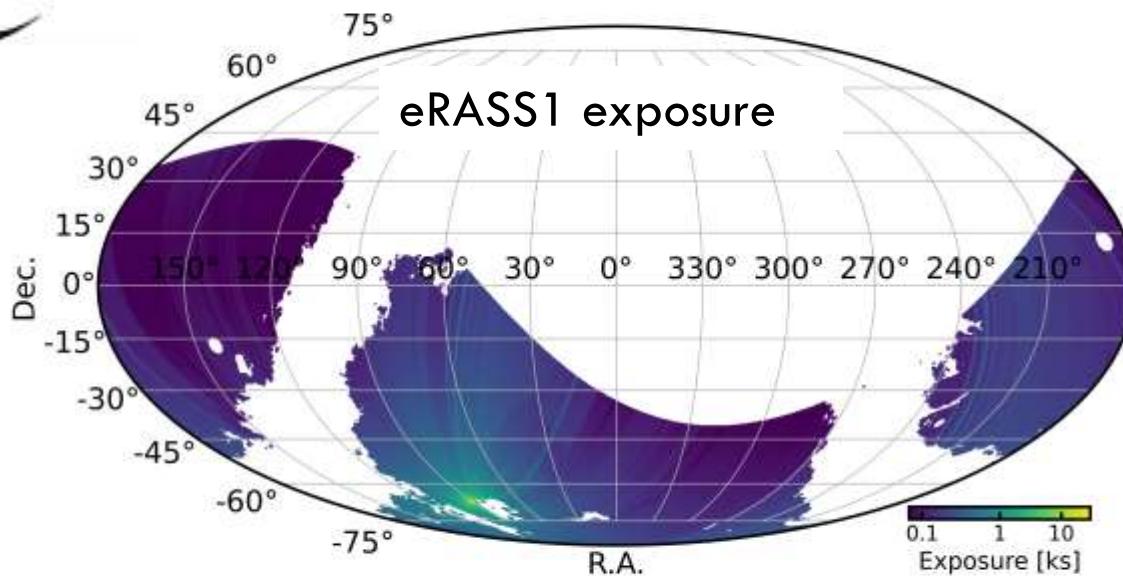


Merloni, X-ray 60, 06/2022

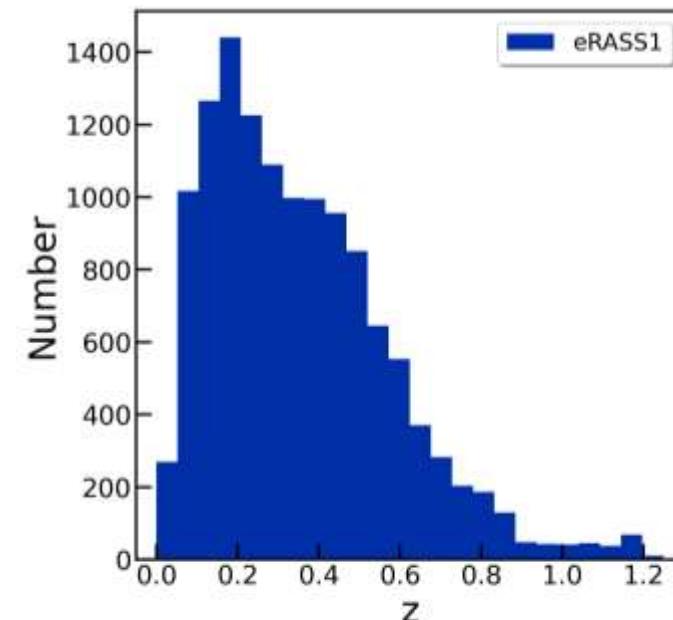
## Extra-galactic source density

- Highly pure and complete flux-limited sample
- 238k non-stellar sources
- Source density closely traces galactic absorption

# The clusters content of eRASS1

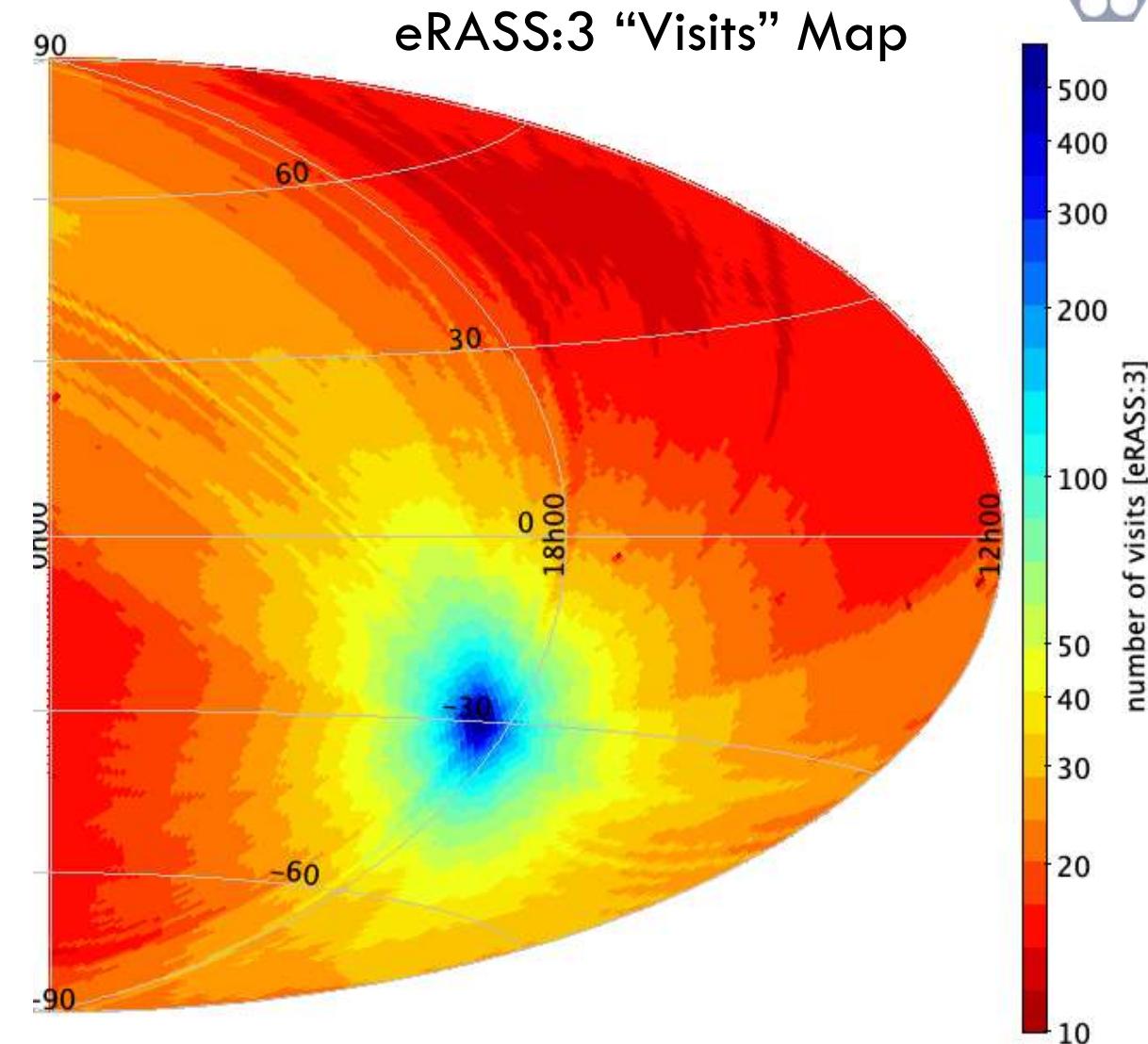


**A. Liu, E. Bulbul, J.  
Ider-Chitham, V.  
Ghirardini, J.  
Sanders and the  
eROSITA Cluster  
WG**



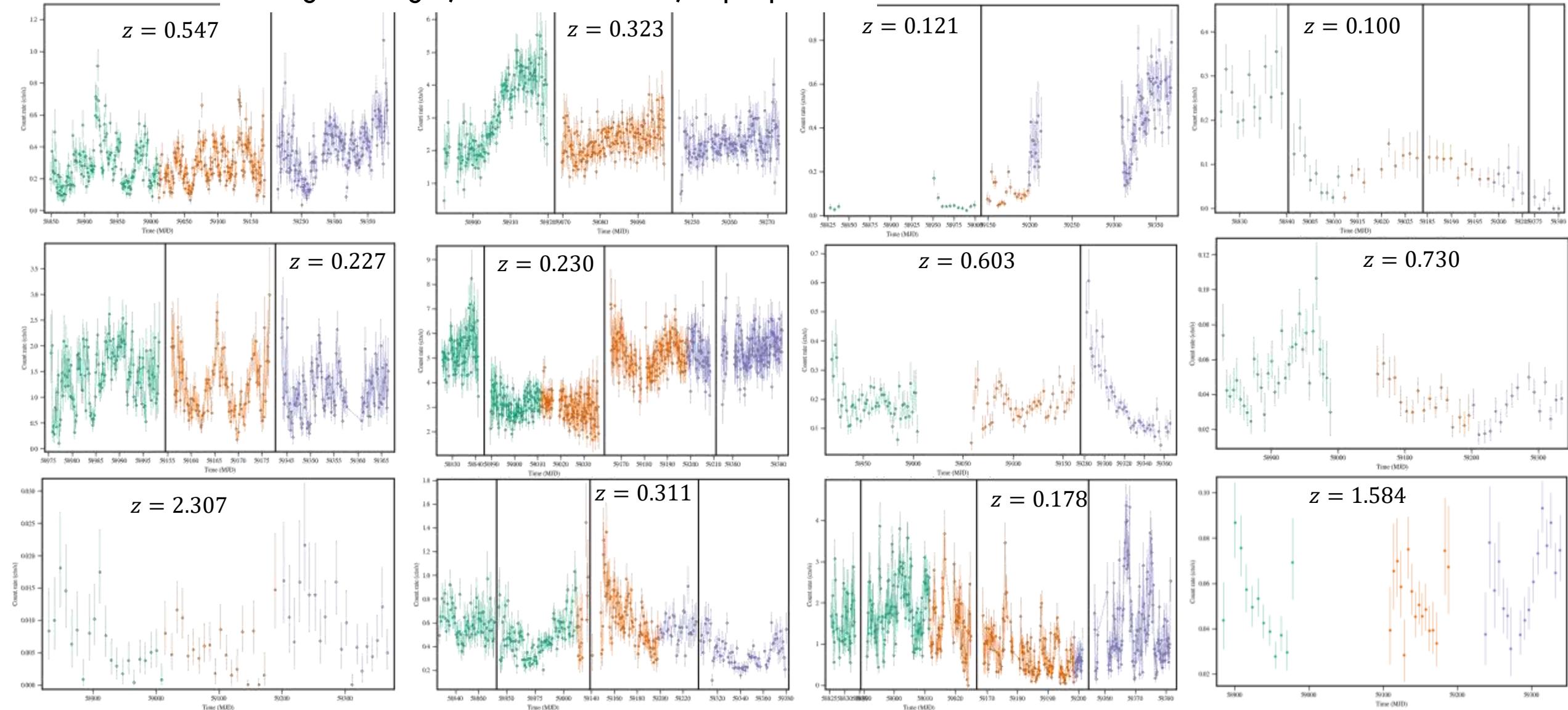
# eRASS: Timescales

- **50 msec [Readout]**: Time resolution of each CCD (frame readout cycle)
- **40 sec [Visit]**: Scan speed + 1 deg. FoV (avg effective exposure)
- **4 hours [eRoday]**: Rotation period of SRG (Interval between scans/visits)
- **1 day [Visibility]**: avg. visibility length ( $\sim 6$  visits)
- **6 months [eRASS]**: one complete all-sky survey (revisit period for most of the sky)
- **4 years**: 8 all-sky surveys



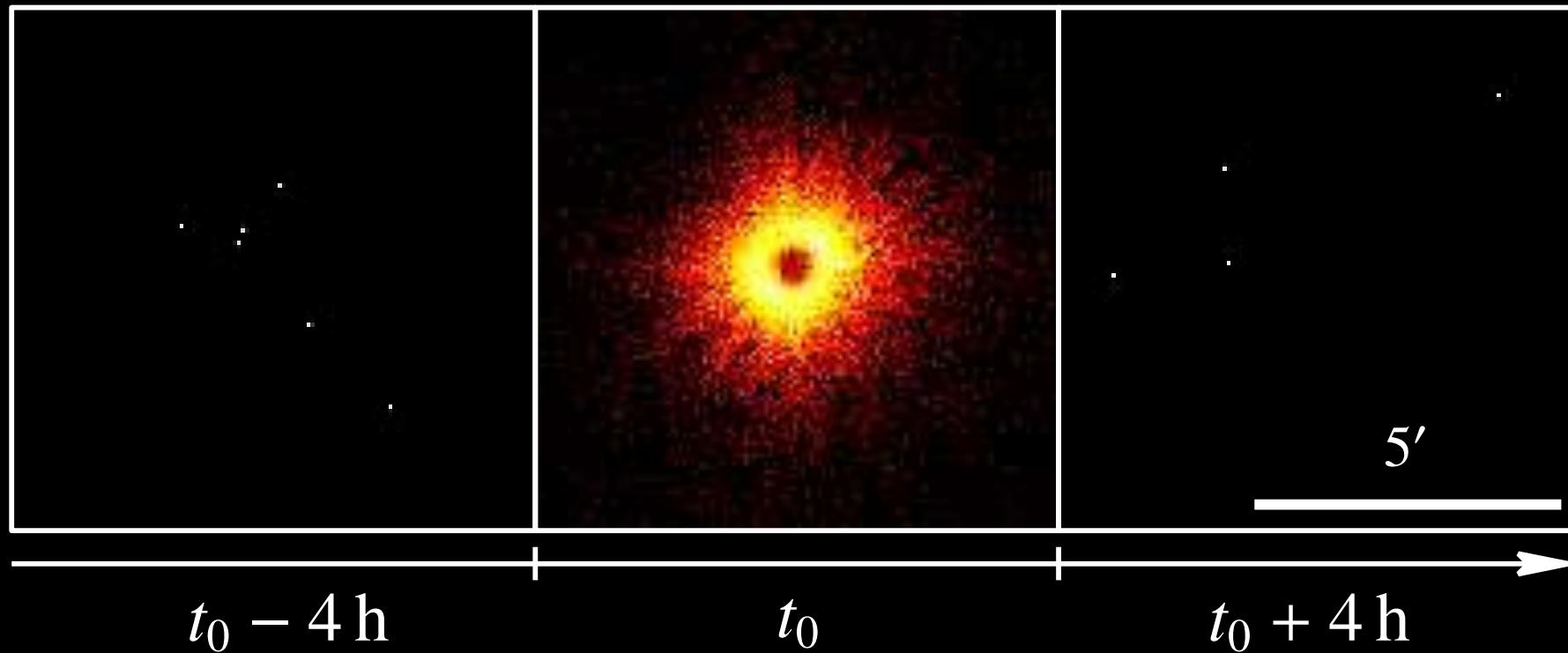
# AGN Light curves in the South Ecliptic Pole

D. Bogenberger, K. Nandra et al., in prep.

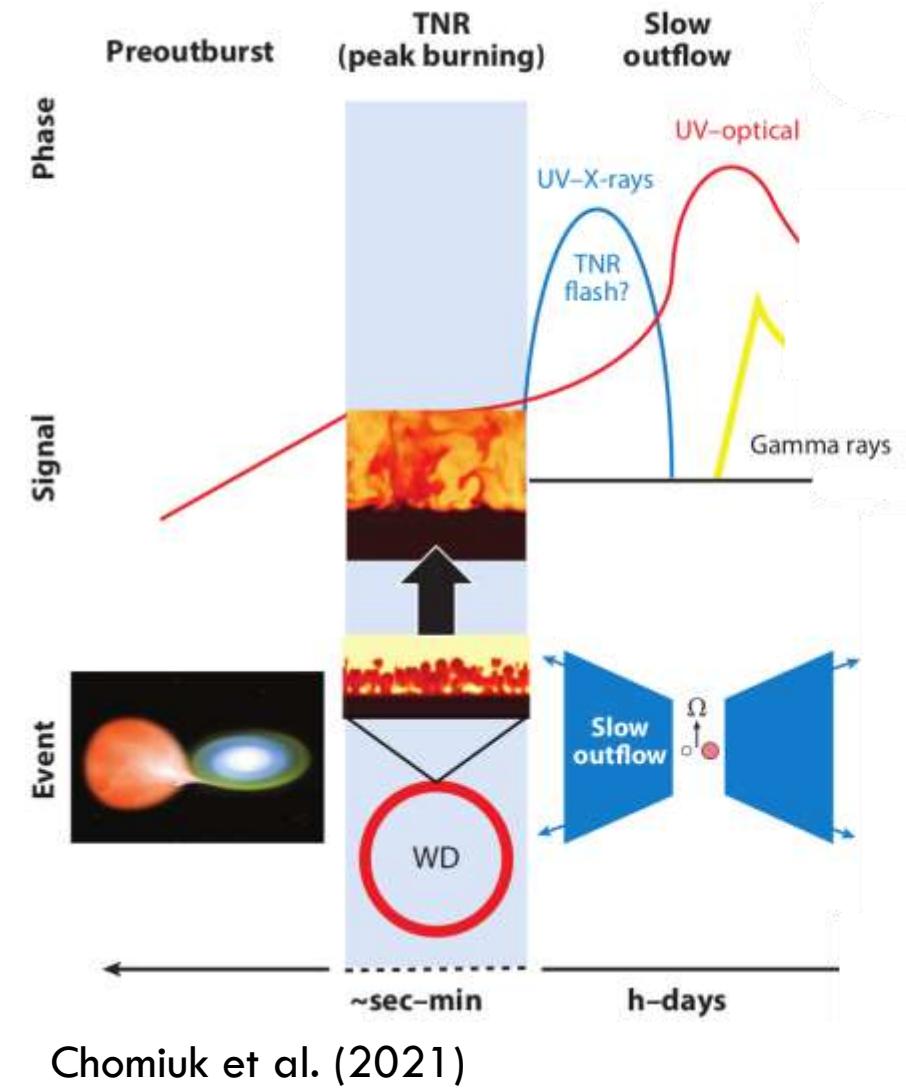
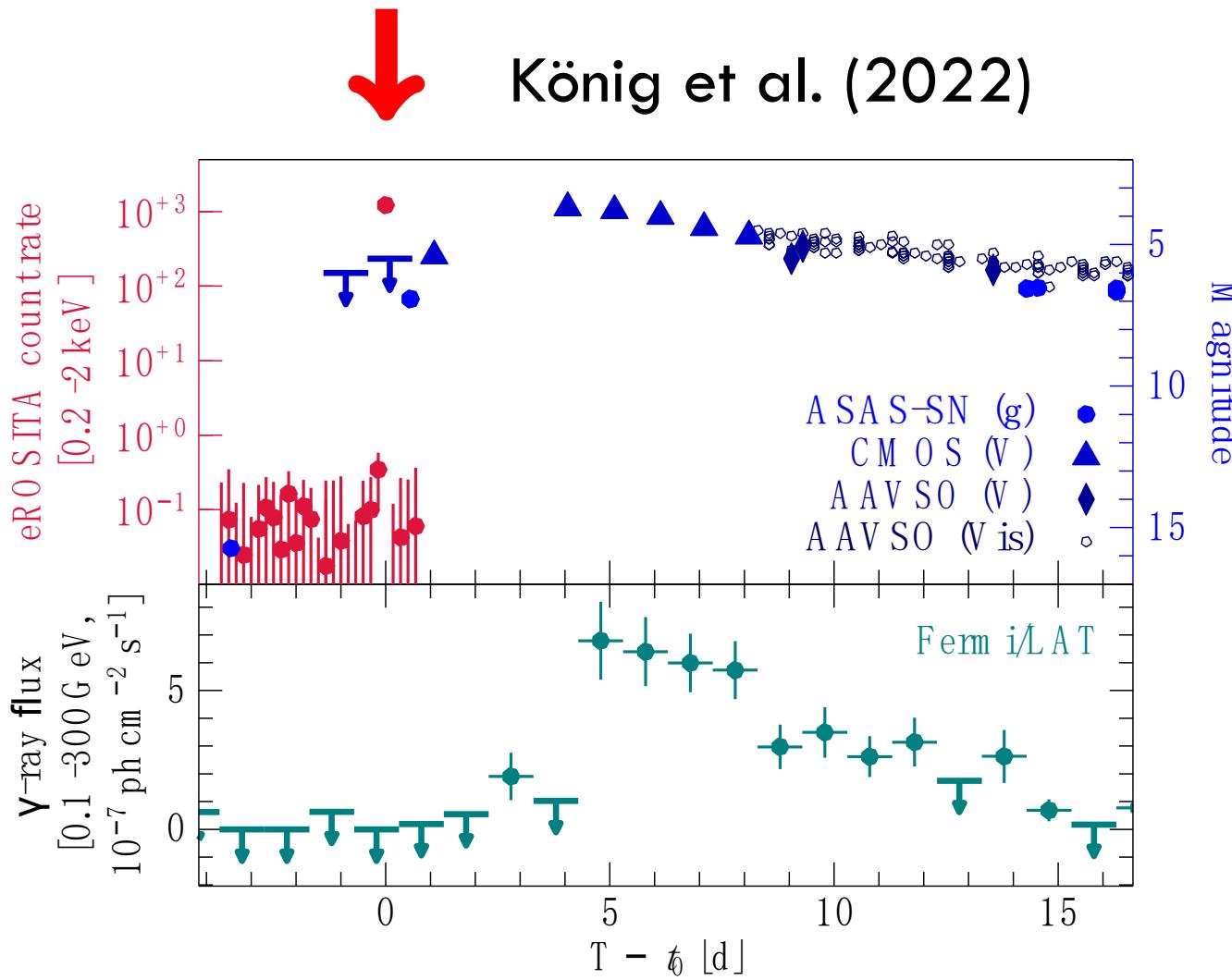


# Discovery of a Nova ignition flash

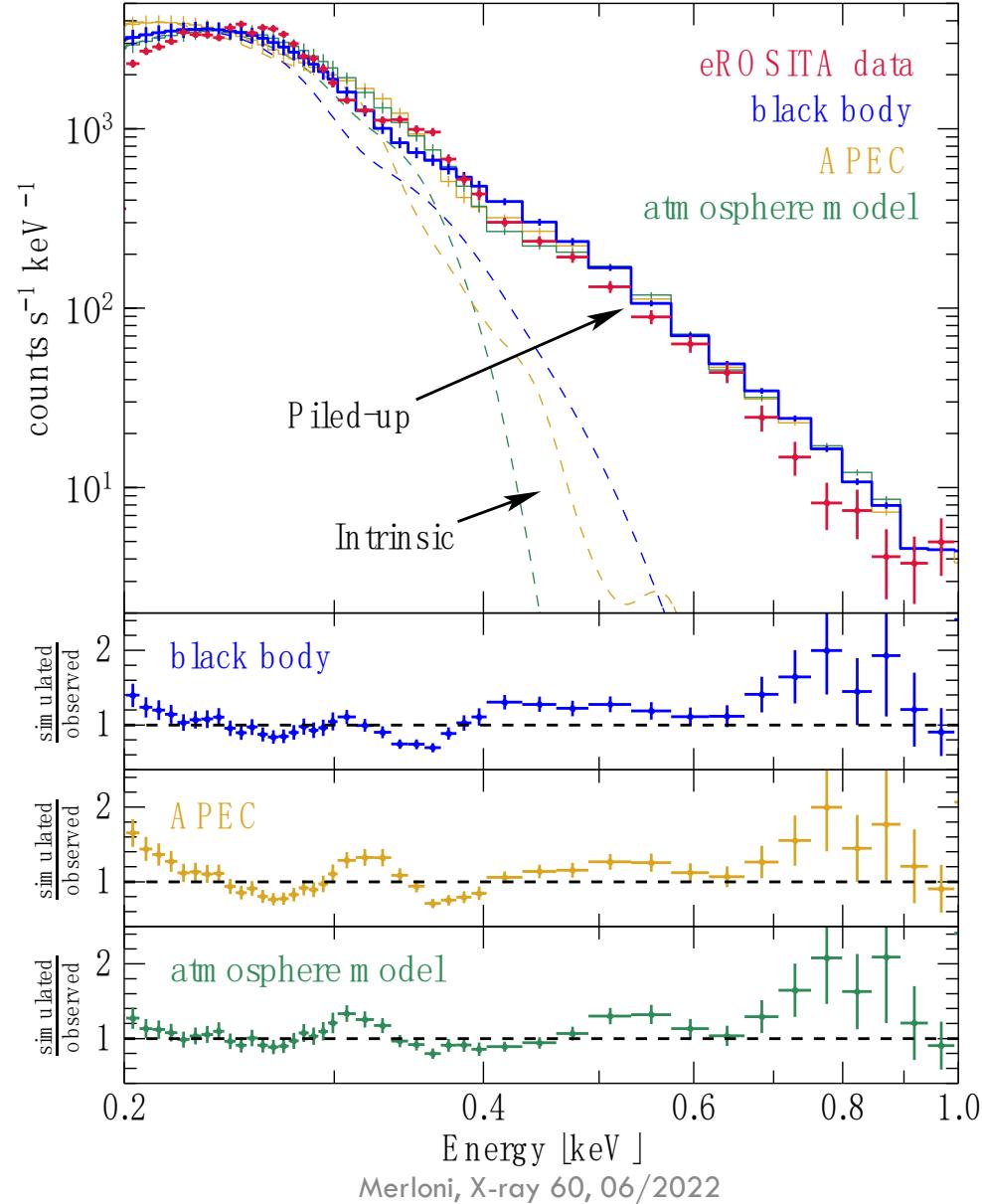
O. König, J. Wilms et al., Nature, in press



# YZ Ret: a Nova ignition flash



# Dealing with pileup: SIXTE simulation





$R_{\text{photosphere}} \sim 50,000 \text{ km}$

*Radiates at  $L_{\text{Eddington}}$*

$KT_{bb} \sim 28 \text{ eV}$

**Heavy**  
White Dwarf  
( $t_{\text{flash}} < 8 \text{ h}$ )

O. König, J. Wilms et al., Nature, in press

Expanding envelope

Merloni, X-ray 60, 06/2022



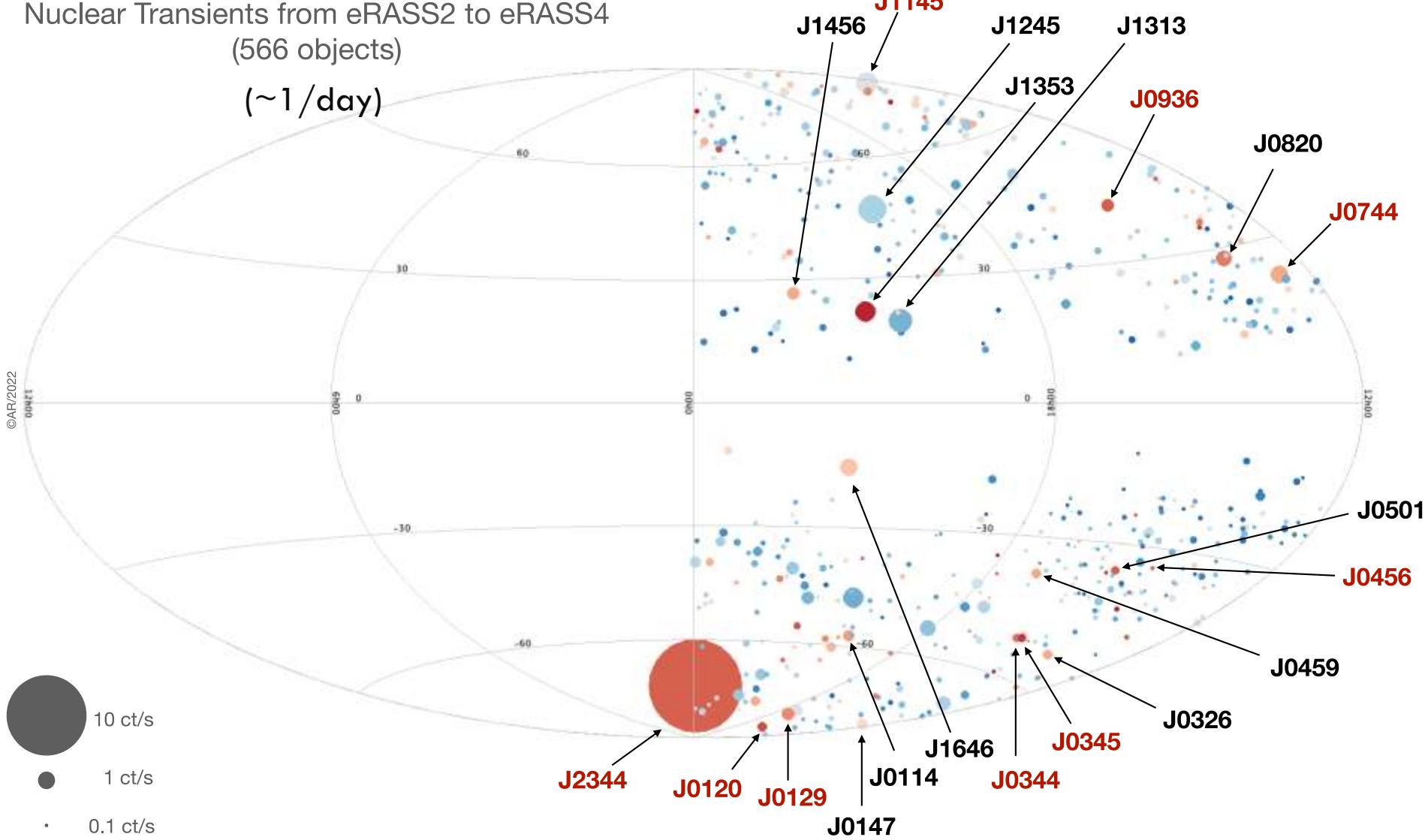
Artist's impression by  
A. Kreykenbohm (Uni. Würzburg)

# Nuclear Transients

Nuclear Transients from eRASS2 to eRASS4  
(566 objects)

(~1/day)

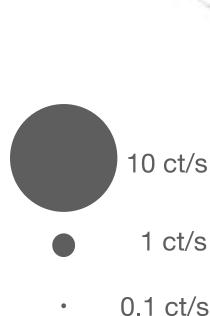
(Credit: A. Rau, A. Malyali, Z. Liu, I. Grotova, MPE)



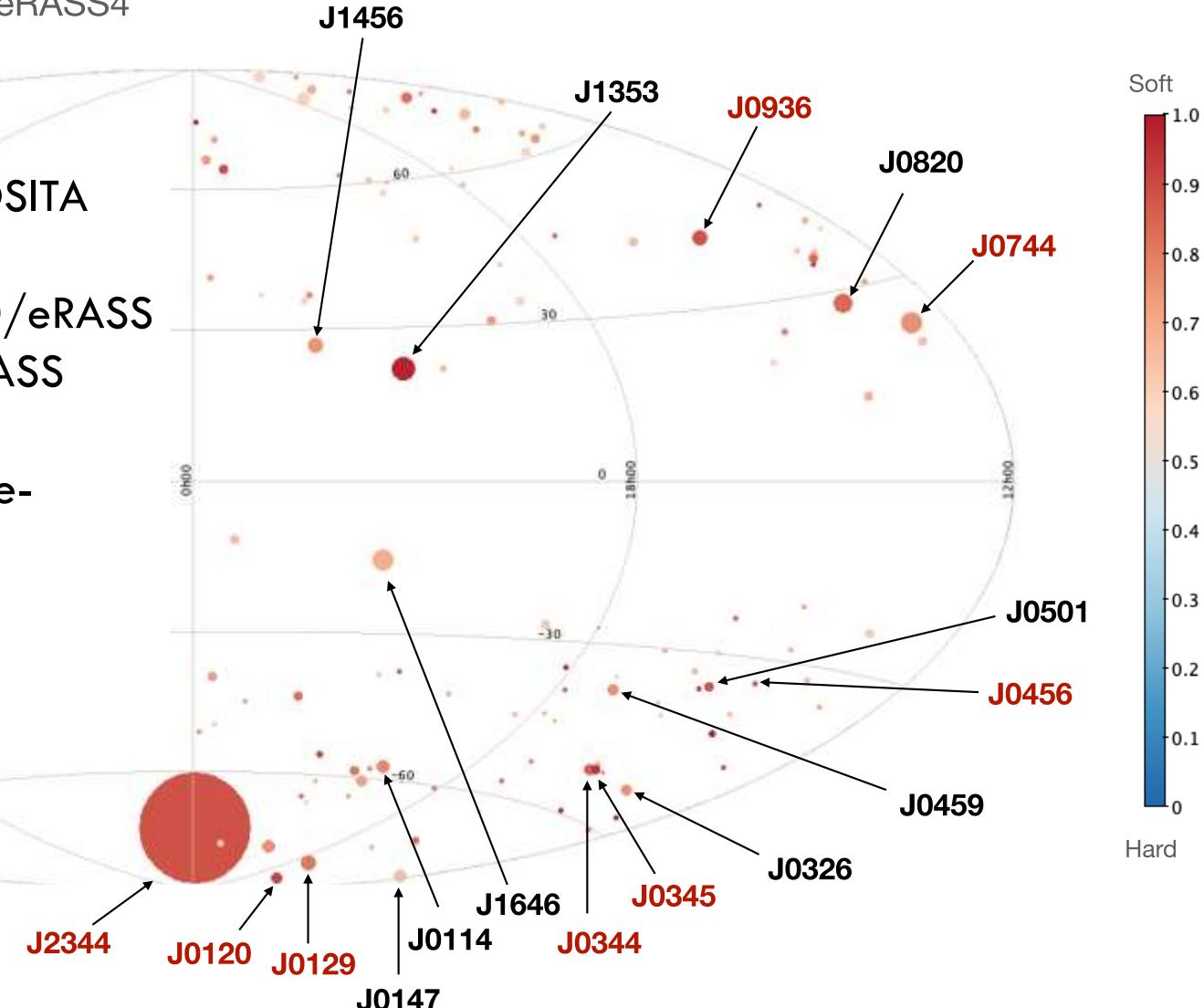
# Soft Nuclear Transients (TDE cand.)

Soft Nuclear Transients from eRASS2 to eRASS4  
(126 objects)  
(~7/month)

- ~20 X-ray-selected TDEs known pre-eROSITA
- Pre-launch eROSITA predictions:
  - Khabibullin et al. 2013: up to 1000/eRASS
  - Thorpe et al. 2019: ~300-450/eRASS
  - Jonker et al. 2020: ~2-500/eRASS
- Wide variety of temporal behaviours (re-flaring, oscillations, etc.)

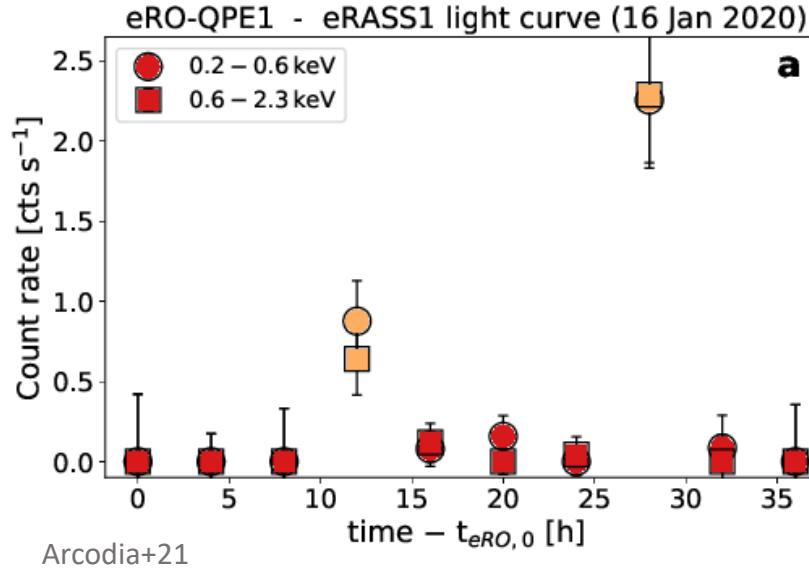


(Credit: A. Rau, A. Malyali, Z. Liu, I. Grotova, MPE)



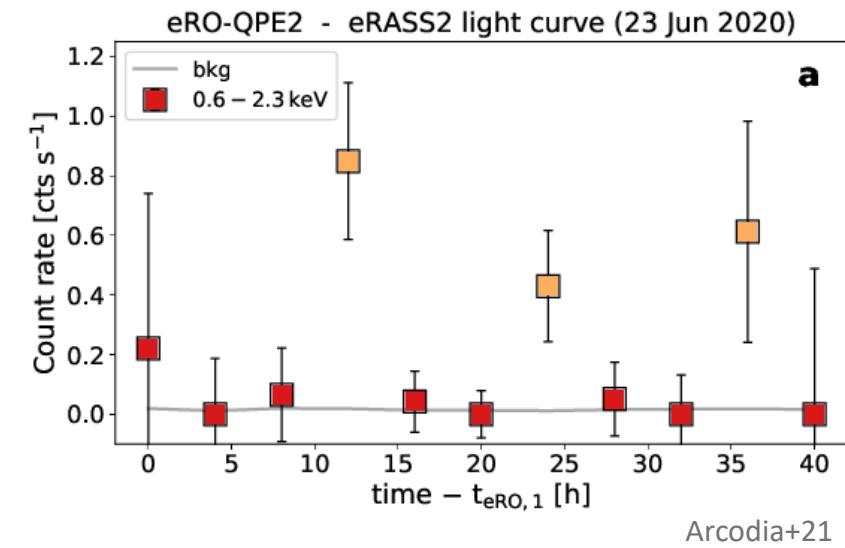
# Quasi Periodic Eruptions (QPEs)

QPE: Large-amplitude, periodic outbursts in AGN discovered by Miniutti et al. 2019 + Giustini et al. 2020



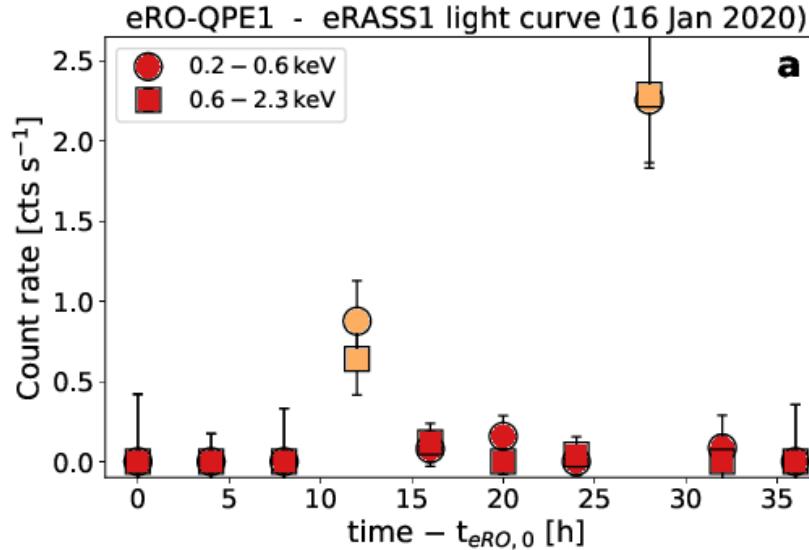
(eRO-)QPE1

QPE2



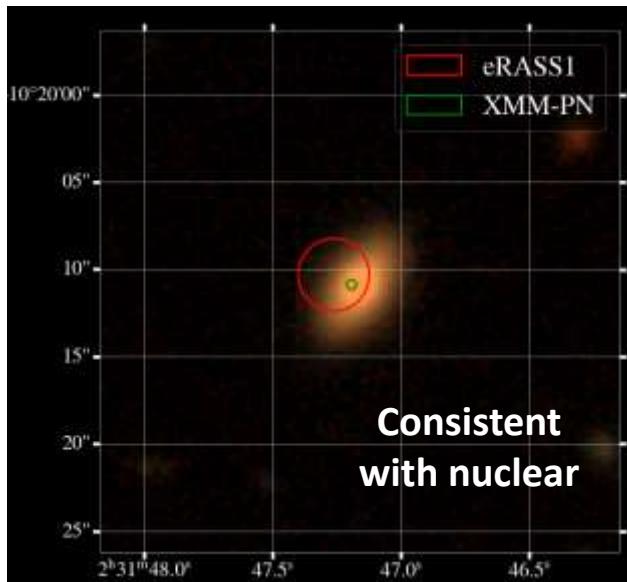
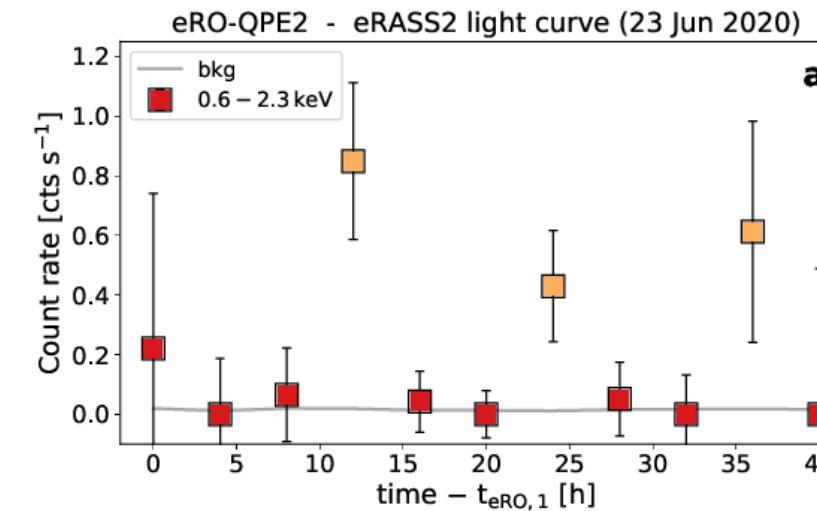
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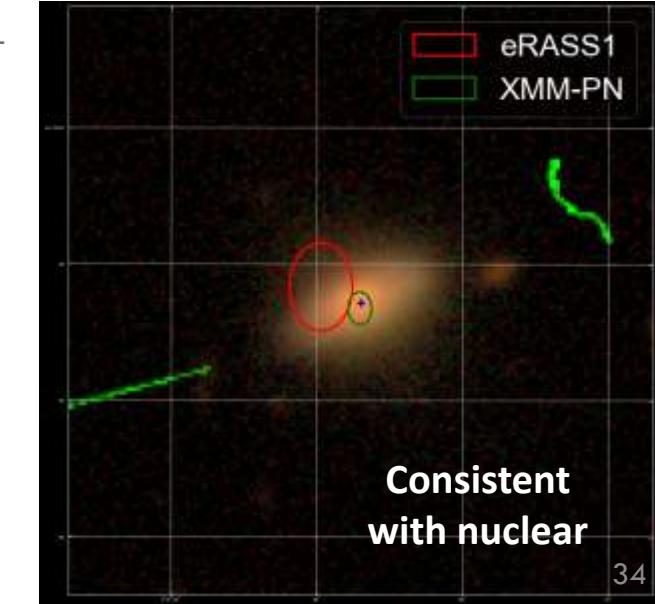


(eRO-)QPE1

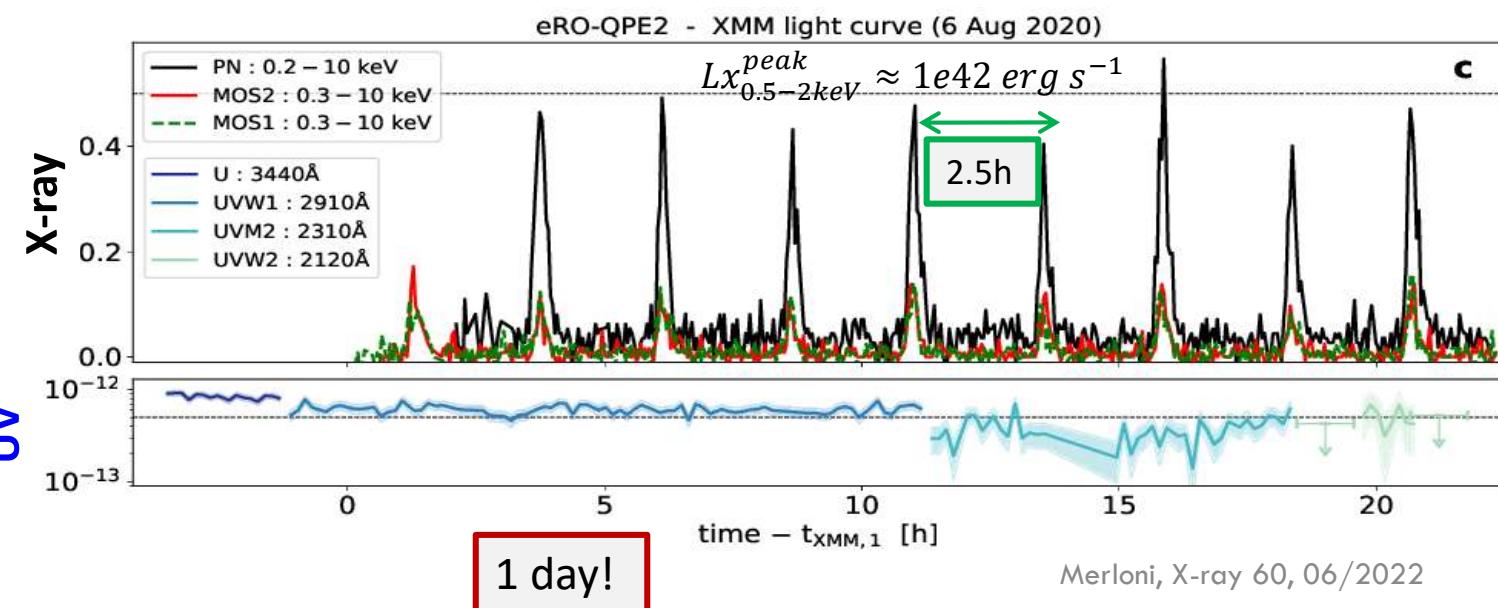
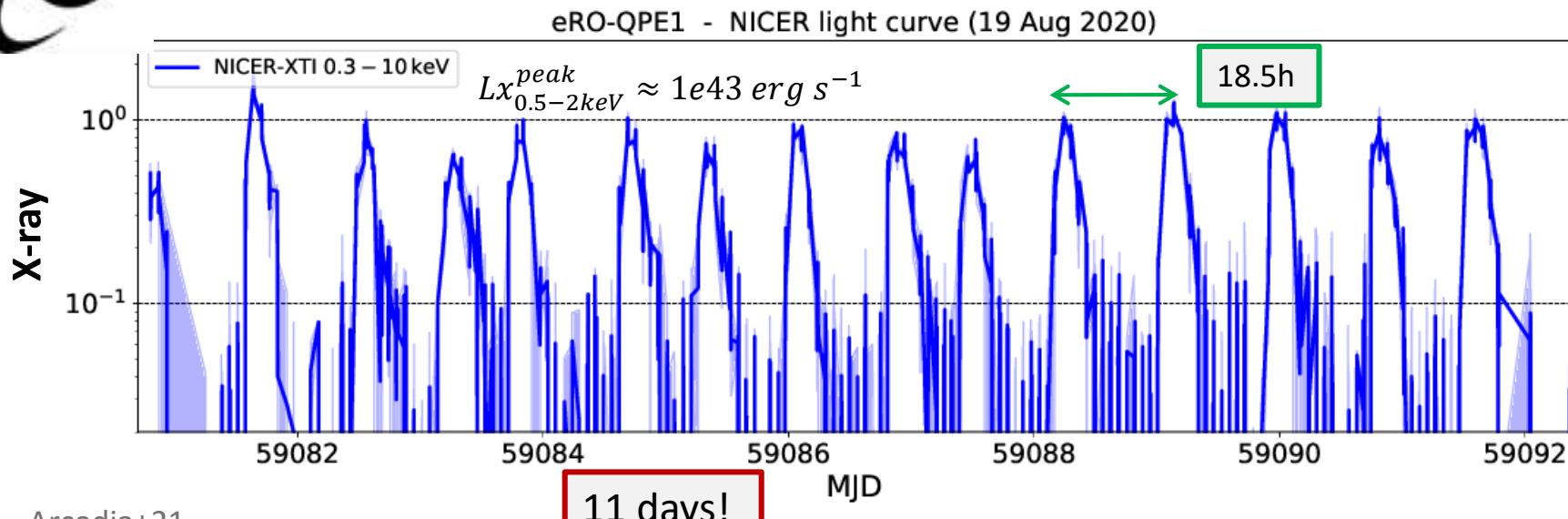
QPE2



Both formerly quiescent low mass  
( $M_* \sim 10^9 M_\odot$ ) galaxies



# QPEs and EMRI



- Unlikely to be “classical” radiation pressure instability of the inner accretion flow (too high amplitude for the observed duty cycle)
- Periodic interaction with an orbiting compact object/star?
  - Eccentric WD-MBH binary (King 2020)
  - Roche lobe overflows of an evolved star orbiting an SMBH (Zhao et al. 2021)
  - Interacting stellar (double) EMRIs (Metzger et al. 2021)
- Implication for mHz GW bkgnd (Chen+ 2021)

Arcodia et al., Nature, 2021

# Conclusions

eROSITA on SRG has been in operation since more than 2 years. All subsystem are working with minimal losses. We have completed 4.4 all-sky surveys

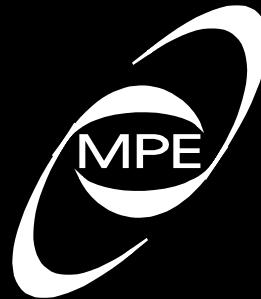
eROSITA is in safe mode since 26.2. Science operations suspended. If/when they will resume is unclear

Thanks to its large Grasp, stable background and observing cadence eROSITA opens up new parameter space for X-ray astronomy across different source classes

eFEDS demonstrates the all-sky survey design requirements can be met

The completed all-sky survey will represent a unique legacy dataset that will be unsurpassed for many years

First all-sky survey data release coming in Q1 2023



[www.mpe.mpg.de/eROSITA](http://www.mpe.mpg.de/eROSITA)



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Thank you

