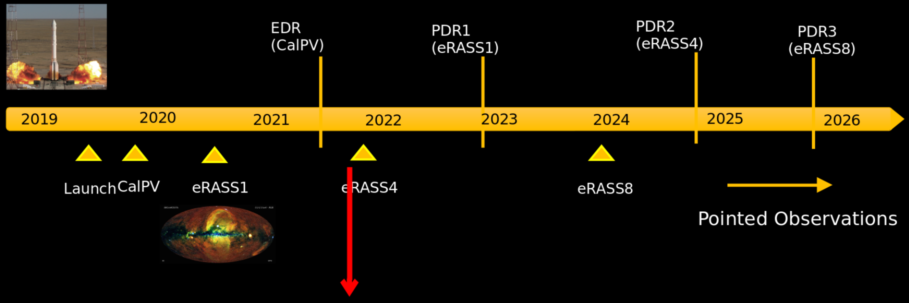
First eROSITA results on Galaxy Groups and Clusters

Vittorio Ghirardini

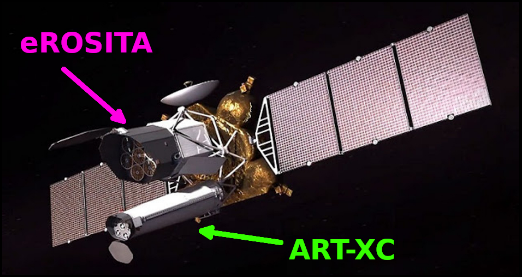
eROSITA Timeline



We are here!

EDR = Early Data Release (June 28, 2021)
PDR = Public Data Release

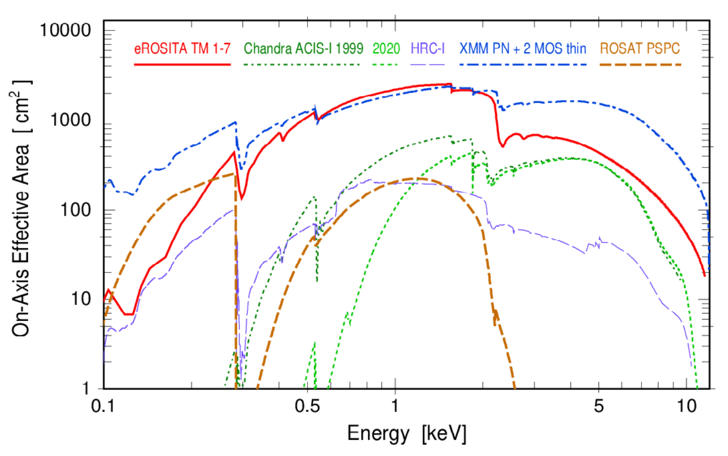
eROSITA on SRG



- 7 mirrors and 7 pnCCD
- Spectral resolution: 75-82 eV FWHM at 1.49 keV
- Focal length 1.6m
- FoV 1 deg diameter
- HEW 18" on-axis, 26" FoV avg.
- Baffles 92% reduction straight light

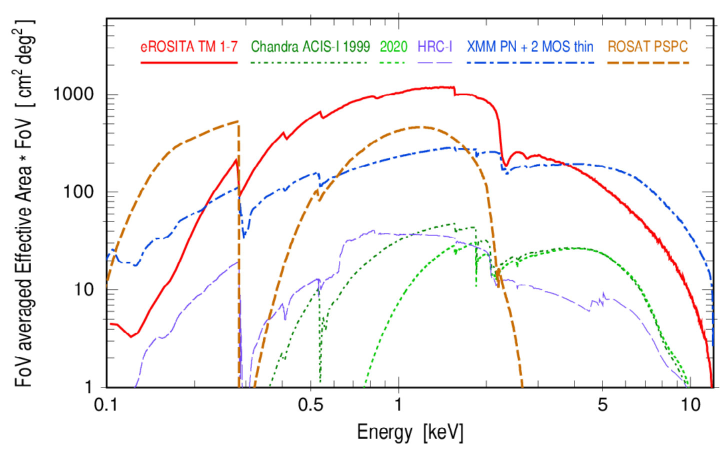
eROSITA Effective Area

- Effective Area: $\sim$1300 cm^2 (FoV average at 1keV)



Predehl+20

eROSITA Grasp

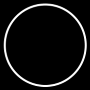


Predehl+20

eROSITA advantages for clusters

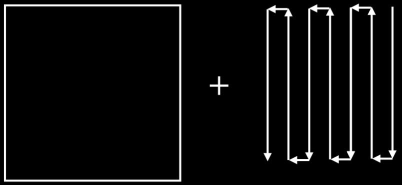
Moon diameter
30 arcmin

XMM-Newton
Field of view ~ 30 arcmin



Chandra
Field of view ~ 17 arcmin

eROSITA
Field of view ~ 65 arcmin



Scanning feature

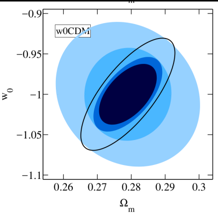
Grasp; FOV*Effective Area @1keV:
- 5×XMM-Newton
- 100×Chandra ACIS

Credit: M. Ramos-Ceja

eROSITA

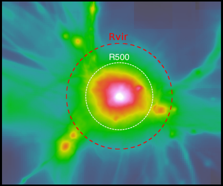
Cluster Astrophysics and Cosmology with eROSITA

Cosmology

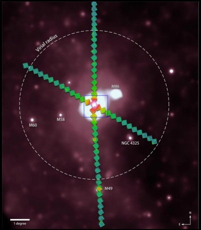


Dark Matter

WHIM



Baryon evolution

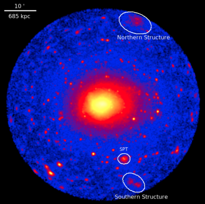


- Map of dark energy (new physics?)
- Nature of dark matter (WIMP, pBH, . . .)
- Inhomogeneity of the Universe
- Baryon evolution

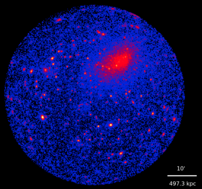
- Chemical enrichment
- Missing baryons
- AGN feedback
- Physics of hot diffuse plasma
- WHIM

Cal-PV program

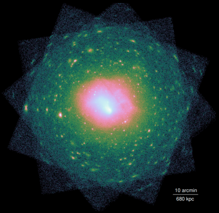
A3158 - Whelan+21

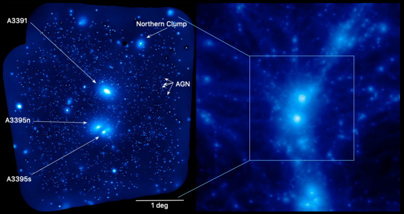


A3408 - Iljenkarevic+21
(AGN 1H0707-495)

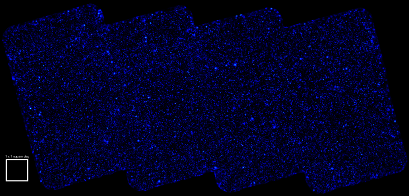


A3266 - Sanders+21





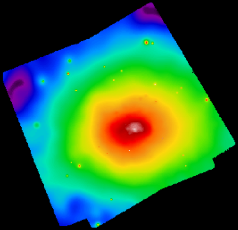
A3391/95 - Reiprich+21 - Biffi+21 - Veronica+21



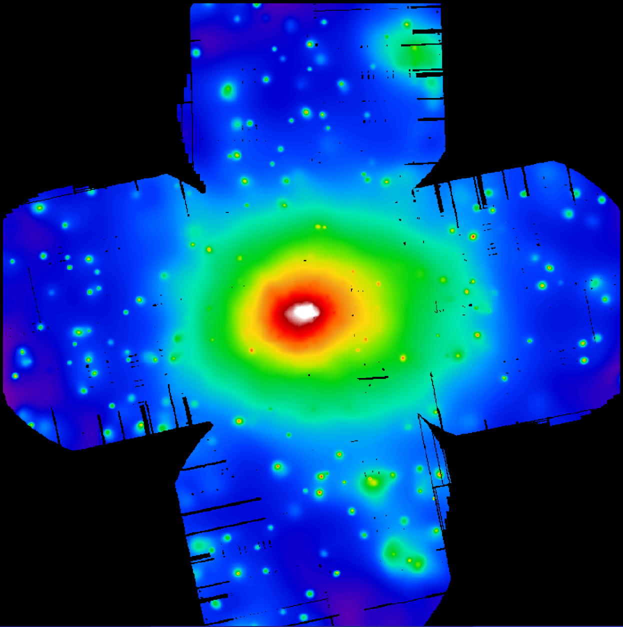
eFEDS

eROSITA

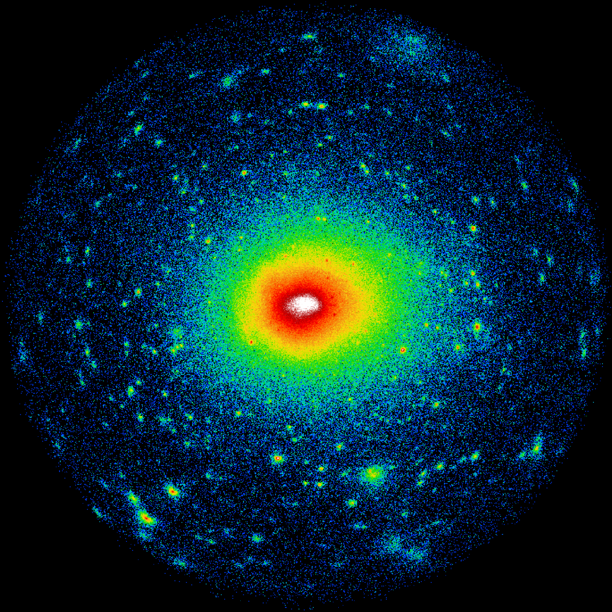
Abell 3158 – Chandra 65 ks



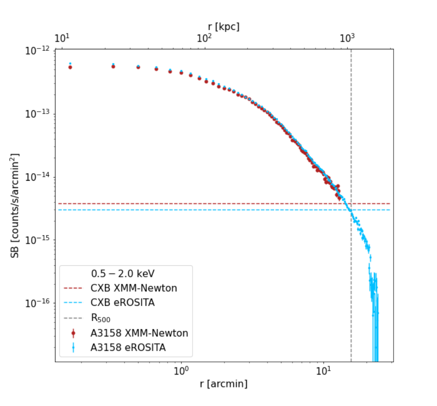
Abell 3158 – XMM-Newton 161 ks

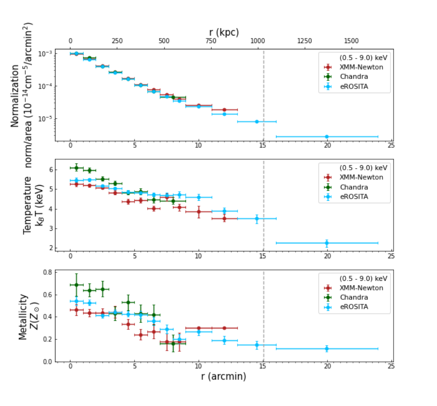


Abell 3158 – eROSITA 80 ks



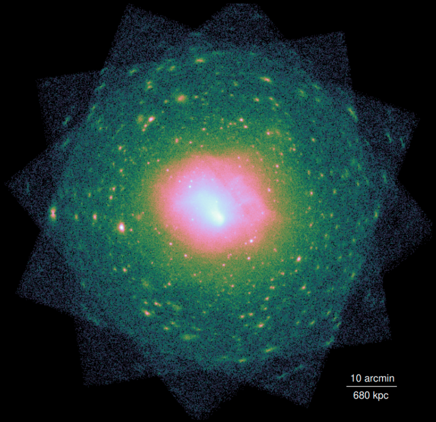
eROSITA analysis

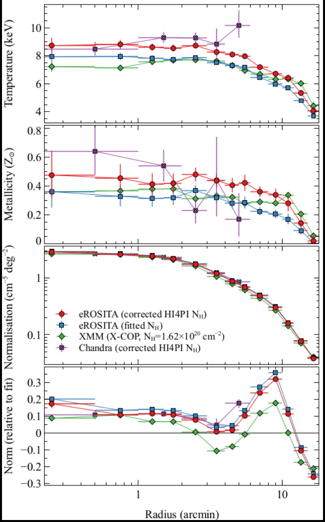




Whelan+21

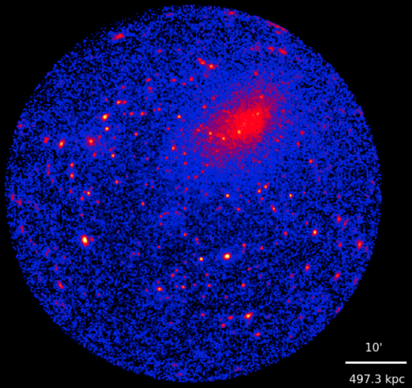
Abell 3266

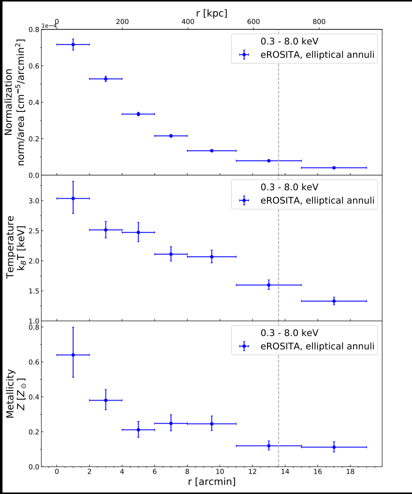




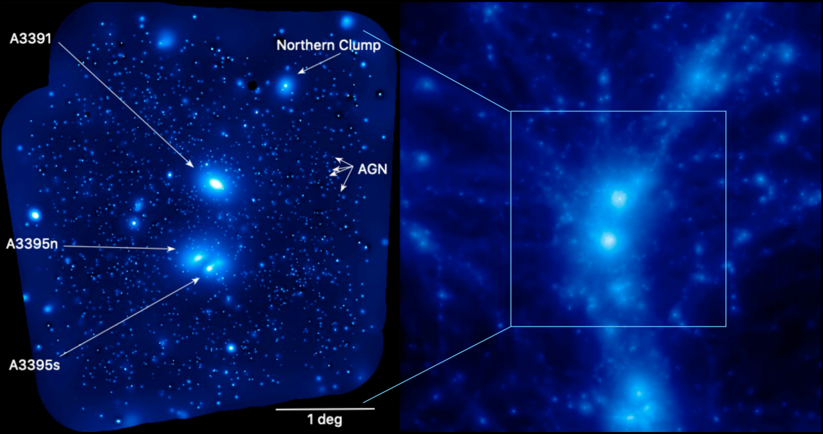
Sanders+21

Abell 3408 (AGN 1H0707-495)



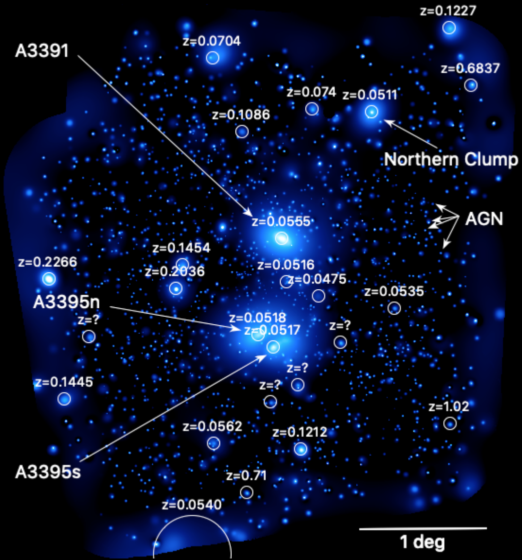


Iljenkarevic+21



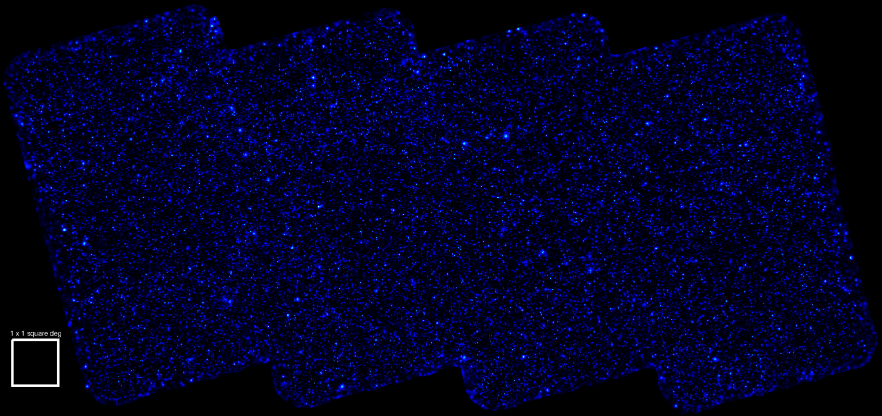
Reiprich+21
Biffi+21
Veronica+21

Abell 3391/95 – 60 clumps detected



Reiprich+21

eROSITA Final Equatorial-Depth Survey



Exposure corrected image in the 0.5–2.0 keV band

MPE/IKI

eROSITA Final Equatorial-Depth Survey

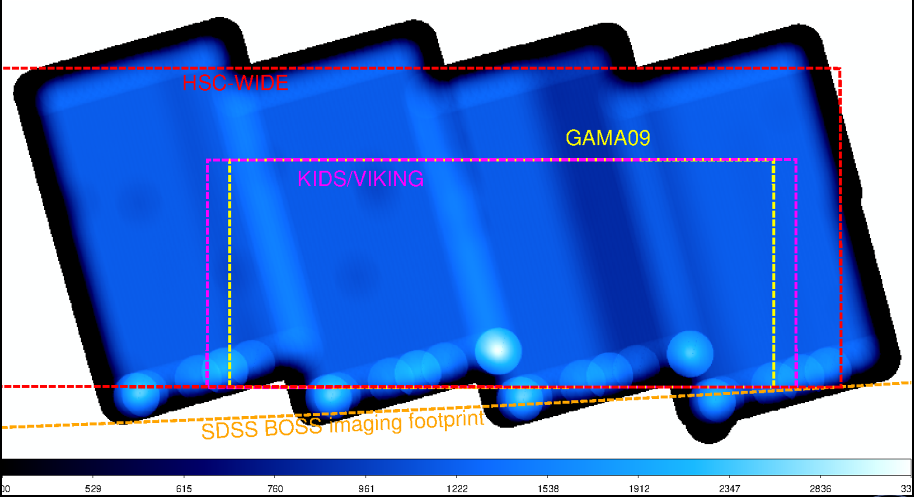
eFEDS

- Proof of concept at final survey depth
- ~540 extended sources detected
- Mass down to $10^{13}\,M_\odot$
- Redshift up to 1.3
- Complete Coverage with HSC, GAMA, DeCALS
- Dedicated SDSS-IV and V plates
- Radio follow-up with LOFAR and uGMRT
- Dedicated NIKA2 and XMM-Newton observation

Exposure corrected image in the 0.5–2.0 keV band

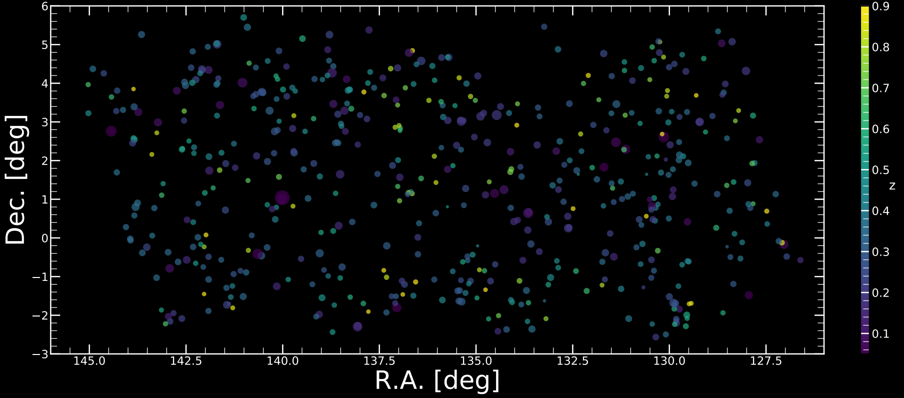
MPE/IKI

eFEDS



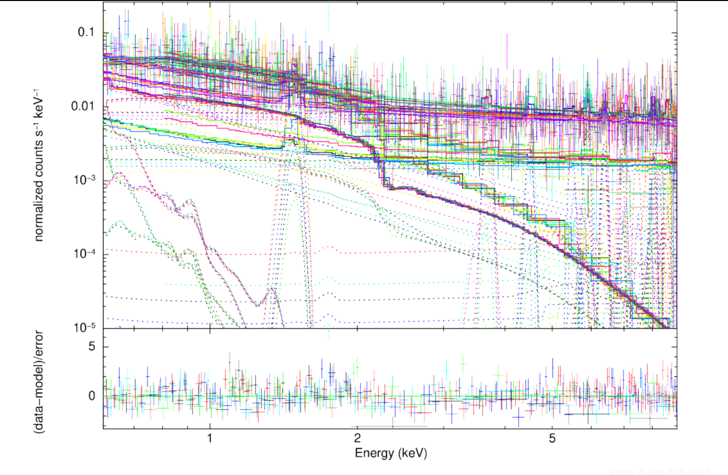
Brunner+21

eFEDS – Extended sources



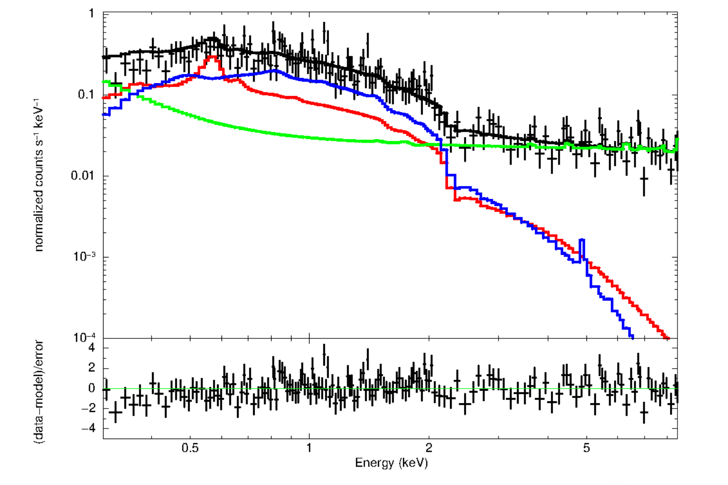
Spectral Analysis

7 TMs with Cluster + CXB + NXB



Spectral Analysis

7 TMs with Cluster + CXB + NXB

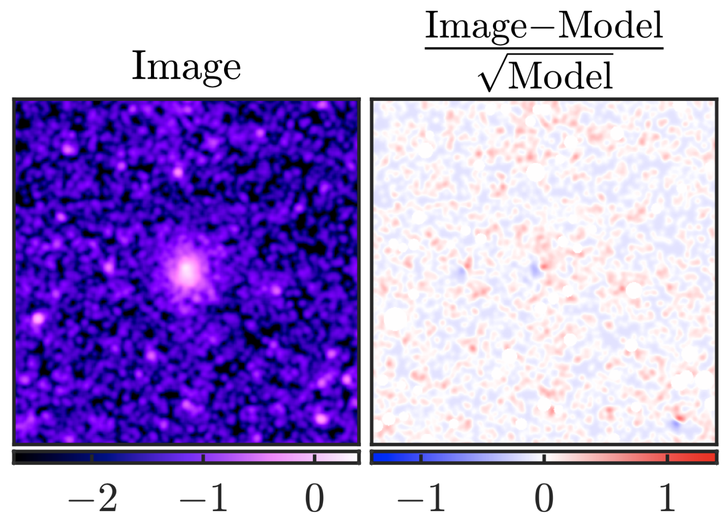


Imaging Analysis – 2D fitting

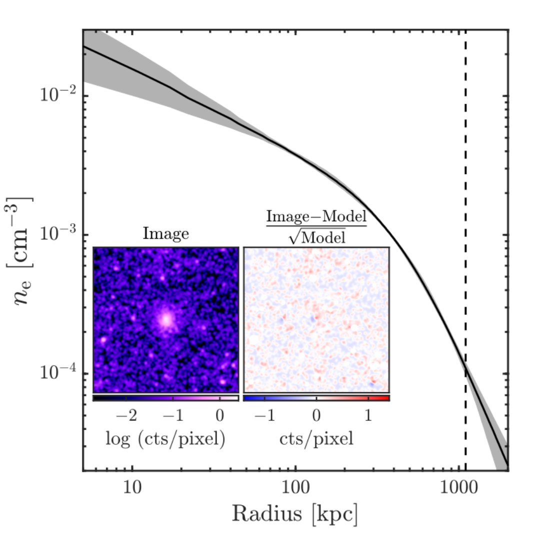
$$\text{Model-Image} = \text{PSF}\#(\text{Cluster} + \text{CXB}) \times \text{EXP}_v + \text{NXB} \times \text{EXP}_{nv}$$

- Centroid variation
  - Needed when few photons
- Vikhlinin+06 density model
  - Allows for many different density models
- PSF accounted
  - Straightforward in 2D analysis
- Drawback: slower to fit

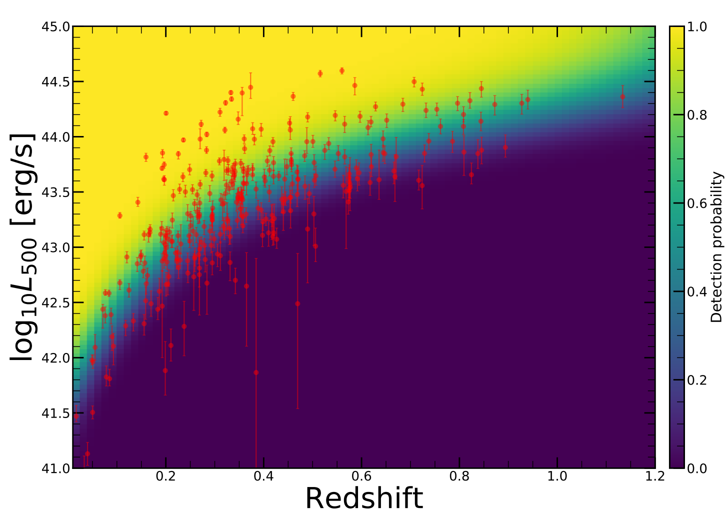
Imaging Analysis



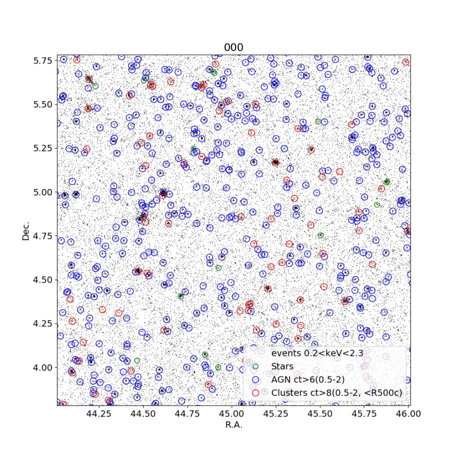
Imaging Analysis

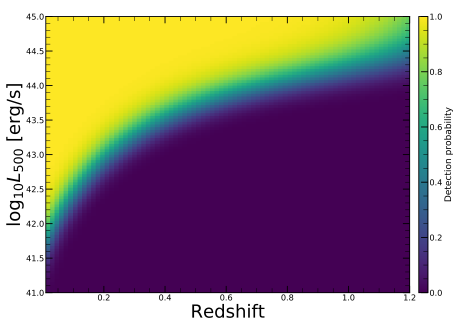


Luminosity vs Redshift



Selection Function using dedicated simulations

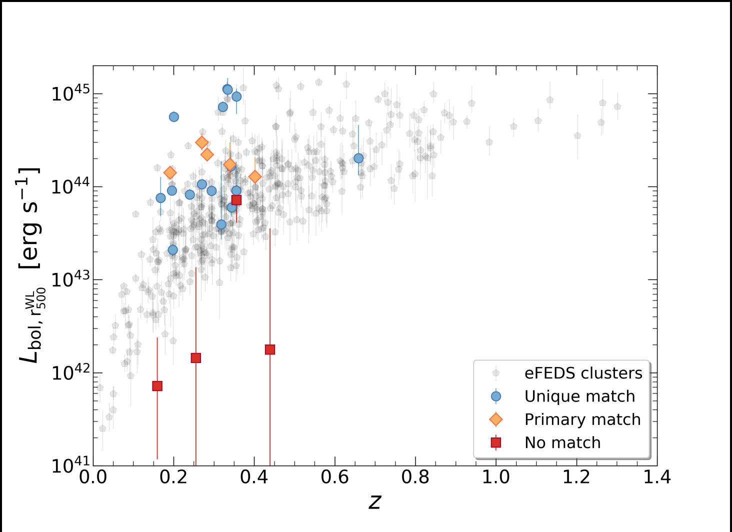




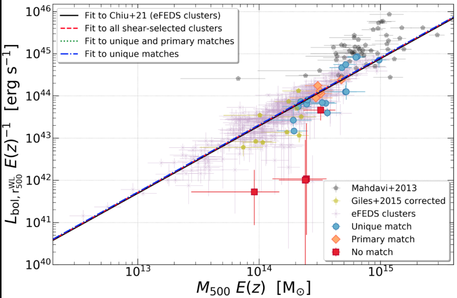
Comparat+21

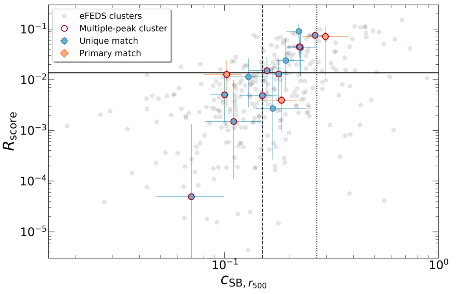
Credit: N. Clerc

Scaling relation and selection effects



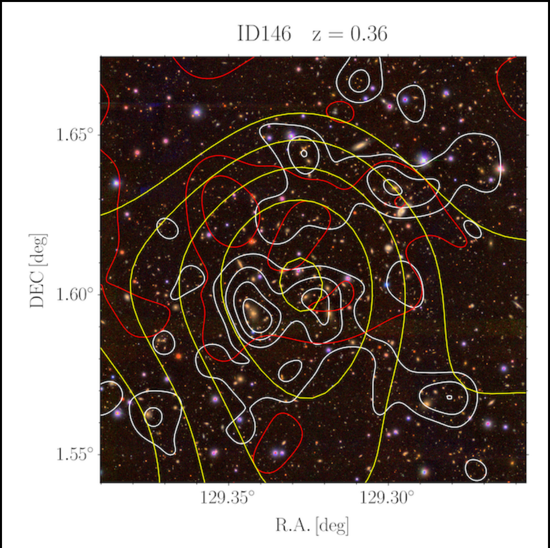
Ramos-Ceja+21





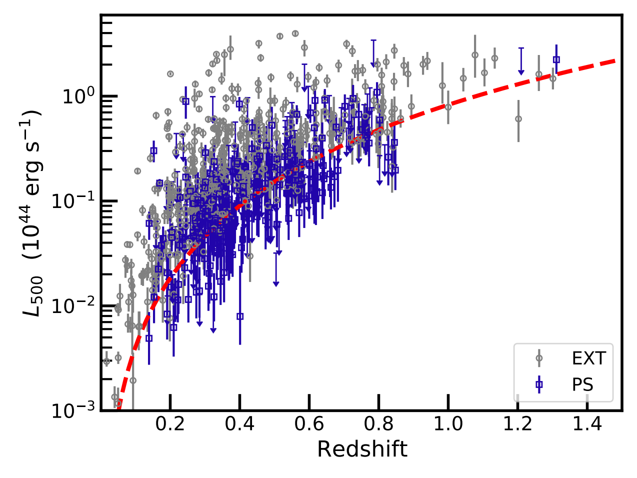
Ramos-Ceja+21

Scaling relation and selection effects



- Comparison of WL Selection with X-rays

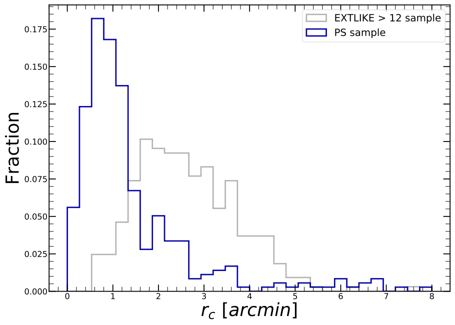
Clusters in disguise

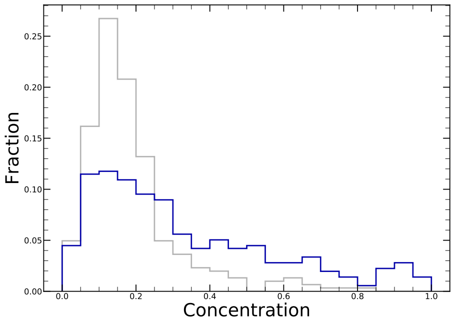


- 357 out of 27k point-like

Bulbul+21

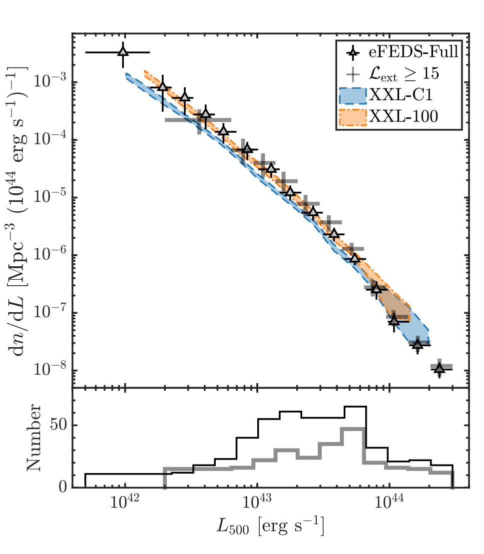
Clusters in disguise





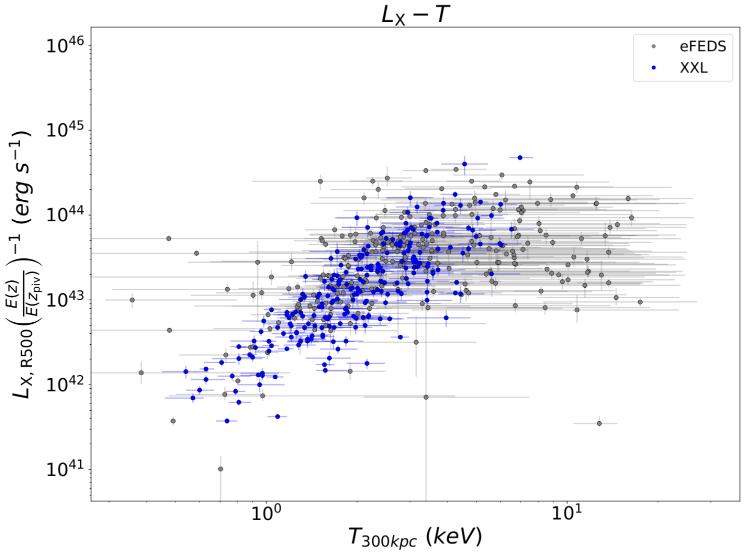
Bulbul+21

X-ray luminosity function



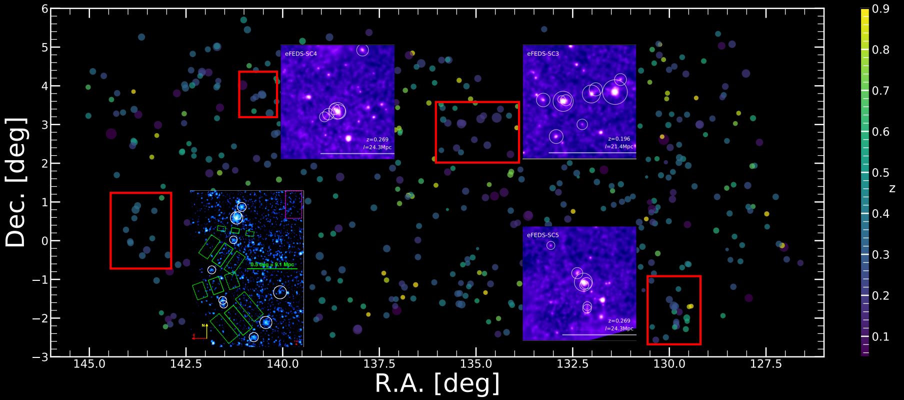
Liu+21

eFEDS – XXL comparison



Credit: Y. E. Bahar

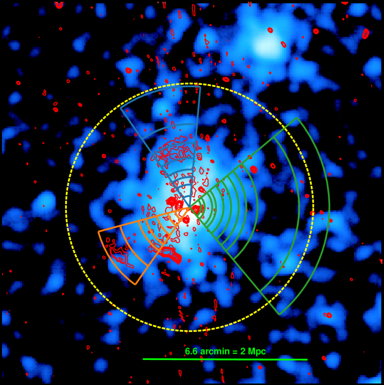
eFEDS – Superclusters

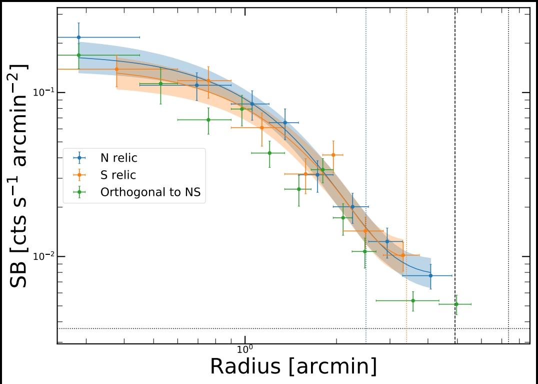


- 19 superclusters Y. Özsoy

Liu+21

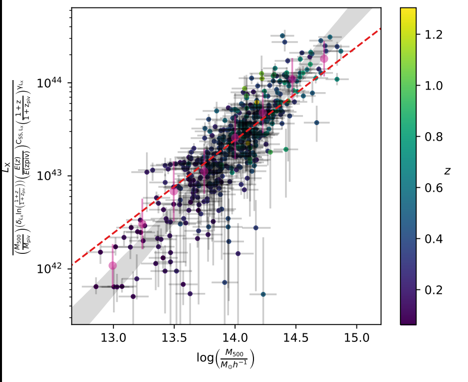
First Supercluster

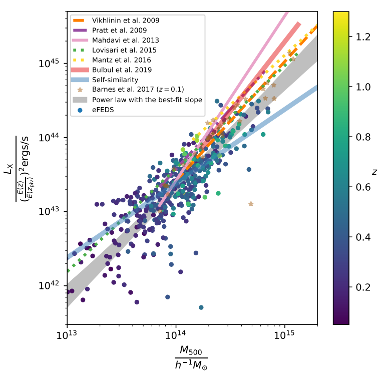




Ghirardini+21

Mass Calibration

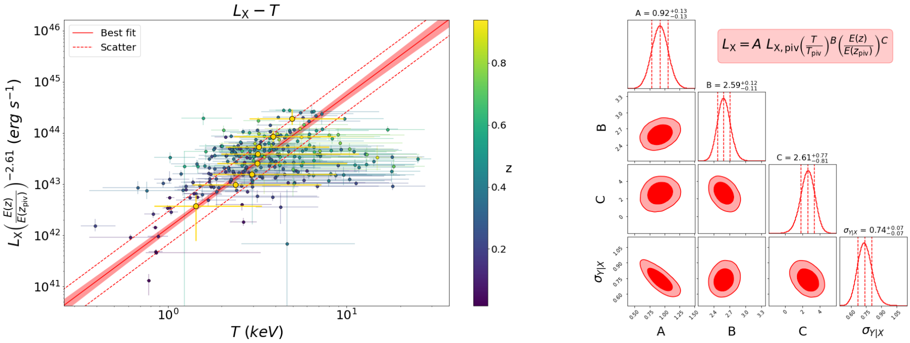




Chiu+21

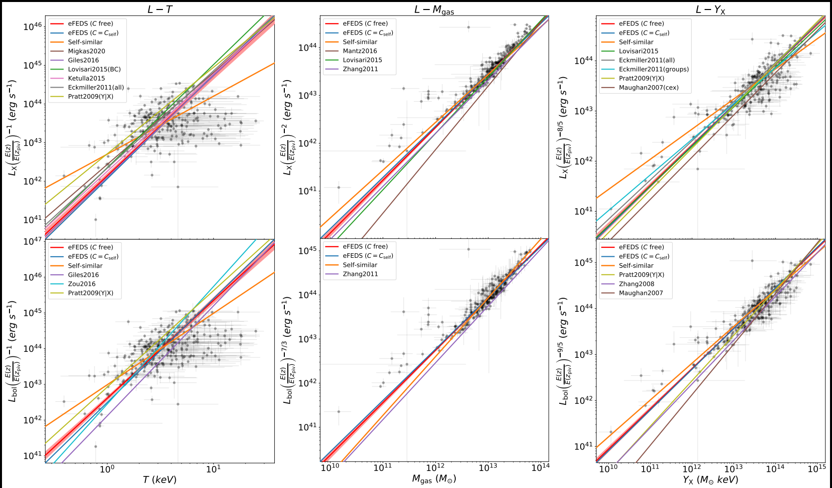
eROSITA

eFEDS – L – T relation



Bahar+21

eFEDS – scaling relation comparison



Bahar+21

Morphological parameters

- Concentration $c_{SB} = \frac{S_{\rm B}(<0.1R_{500})}{S_B(<R_{500})}$

  Santos+08

  - how significant is the core emission
  - at $[40 - 400]$ kpc and $[0.1 - 1]$ R_{500}

- Cuspiness $\alpha = \frac{d\log\rho_g}{d\log r}\Big|_{0.04R_{500}}$

  Vikhlinin+07

  - steepness of the density profile at fixed rescaled radius

- Central Density $n_0 = n_e|_{0.02R_{500}}$

  Hudson+10

  - Value of the density at fixed rescaled radius

- Ellipticity ϵ
  - ratio between minor and major axis of the distribution

- Centroid Shift

  $w = \frac{1}{R_{500}}\left[\frac{1}{N-1}\sum_{i=1}^{N}(\Delta_i - \bar{\Delta})^2\right]^{\frac{1}{2}}$

  Mohr+93

  - variance of the centroid of the emission in increasing apertures

- Power ratios P_{m0}

  Buote+95

  - 2-dimensional decomposition of the surface brightness

- Photon asymmetry A_{phot}

  Nurgaliev+13

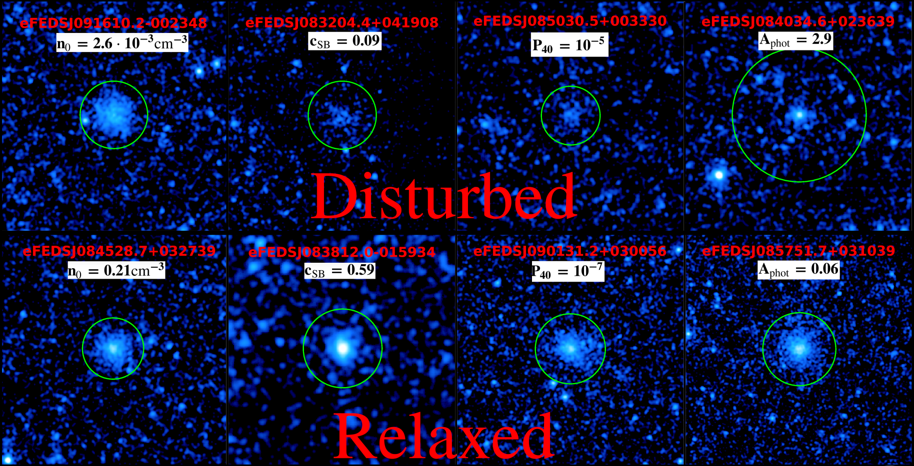
  - difference between measured photon distribution and uniform distribution

- Gini coefficient G

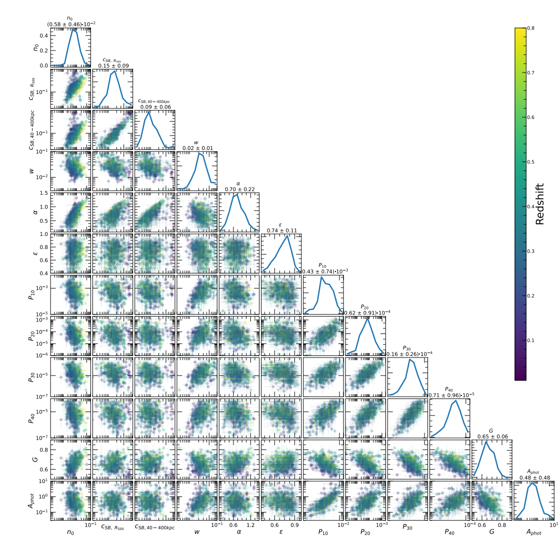
  Loetz+04

  - inequality in distribution of photons among the pixels

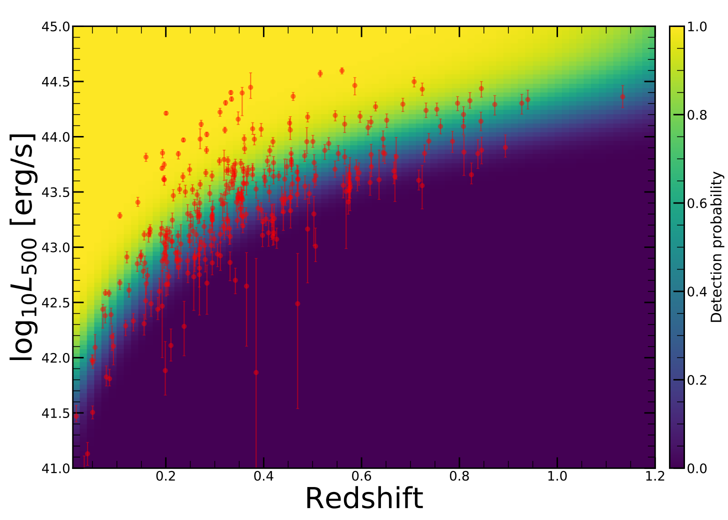
Disturbed vs Relaxed Clusters



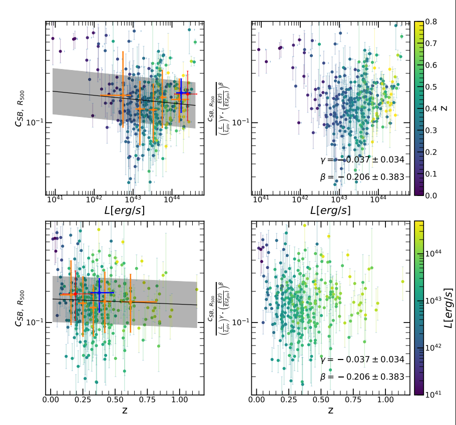
Parameter-parameter distribution

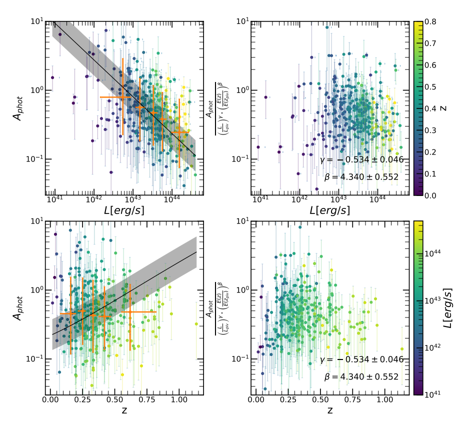


L-z dependence of parameters



Joint Modeling of the Redshift and Luminosity Evolution

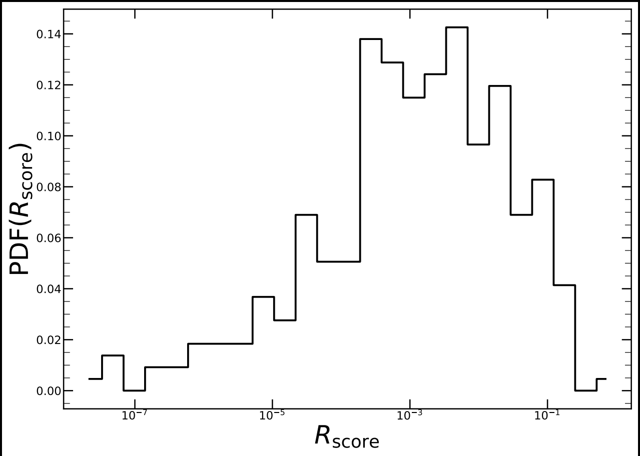




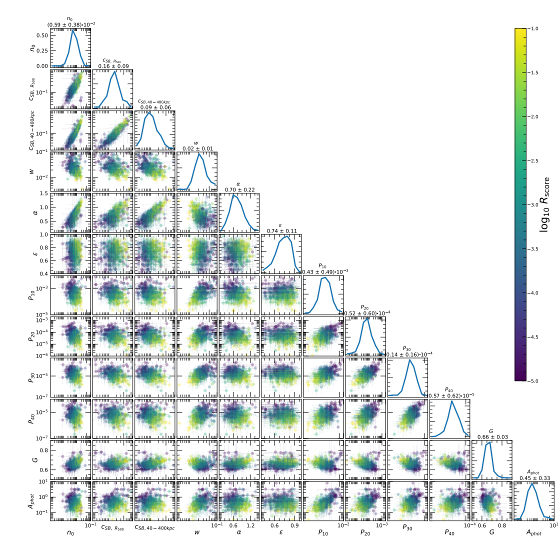
- $\mathcal{M}_{new} = \mathcal{M} \cdot \left(\frac{L}{L_{\text{piv}}}\right)^{-\gamma} \left(\frac{E(z)}{E(z_{\text{piv}})}\right)^{-\beta}$

L and z Independent Morphological Parameters

The new relaxation score: $R_{\rm score} = \int_{-\infty}^{\mathcal{M}_1} \cdots \int_{-\infty}^{\mathcal{M}_n} \mathcal{MN}(\mu, \mathbf{\Sigma}) d\mathcal{M}_1 \ldots d\mathcal{M}_n$

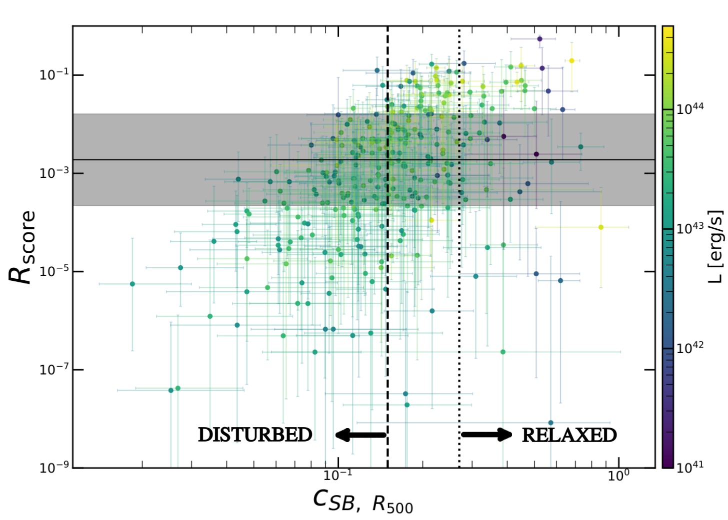


Corrected parameter-parameter distribution



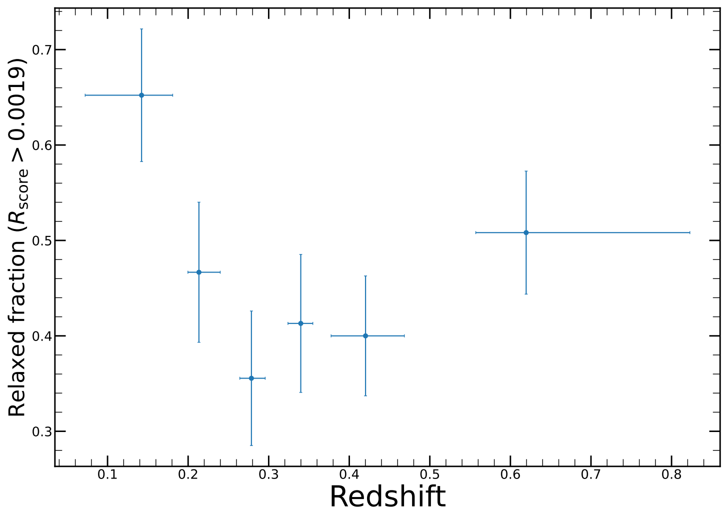
eROSITA

Relaxed cluster fraction



eROSITA

Relaxed fraction evolution



Investigating the bimodality

$$P(\hat{\mathcal{M}}|\theta, \mathcal{D}) = \int P(\hat{\mathcal{M}}|\mathcal{M}) \cdot \mathcal{D}(\mathcal{M}|\theta) d\mathcal{M}$$

Parameter	ΔB_N	ΔB_{2N}	ΔB_{SN}	ΔB_{LN}	ΔB_{2LN}	ΔB_{SLN}
n_0	36.00	5.84	6.47	2.25	3.69	0.00
$c_{SB,\ R_{500}}$	40.83	1.28	7.41	0.00	0.59	0.75
$c_{SB,40-400kpc}$	58.91	7.69	16.06	5.45	2.77	0.00
w	80.18	8.28	22.12	7.38	2.41	0.00
α	1.71	2.63	0.81	0.00	2.63	0.72
ϵ	2.99	0.54	0.00	3.53	0.52	0.29
P_{10}	48.81	7.70	14.58	0.00	1.51	1.26
P_{20}	12.55	2.42	0.00	1.99	0.34	2.11
P_{30}	14.36	4.84	1.95	7.28	0.00	6.26
P_{40}	7.58	5.83	0.00	7.91	1.71	4.27
G	0.00	1.30	0.87	0.19	1.43	0.99
A_{phot}	49.30	2.79	16.28	3.88	0.00	2.62
R_{score}	176.68	22.14	113.24	0.00	2.17	0.47

- Our data prefer single-peak distribution over a bi-modal

Summary

- In eFEDS we detect >4 clusters per deg^2, as expected
- $M > 10^{13} M_\odot$, $z < 1.3$
- Check out https://erosita.mpe.mpg.de/publications/

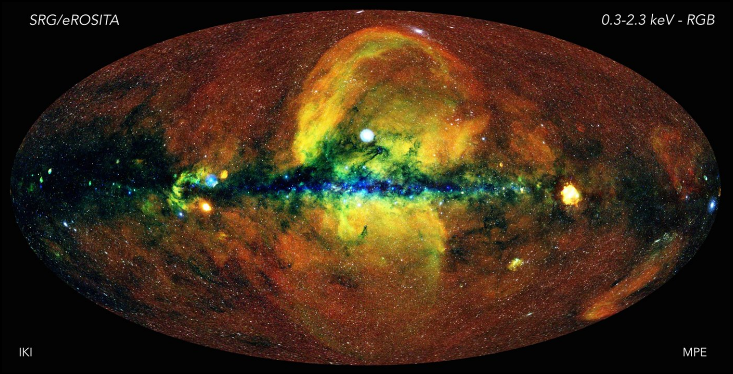
- Contact our working groups

  https://www.mpe.mpg.de/455860/working_groups
- Get the Cal-PV data

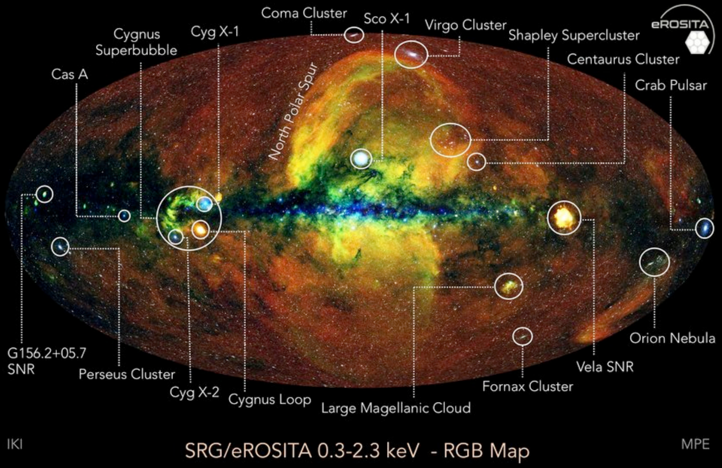
  https://erosita.mpe.mpg.de/

Backup slides

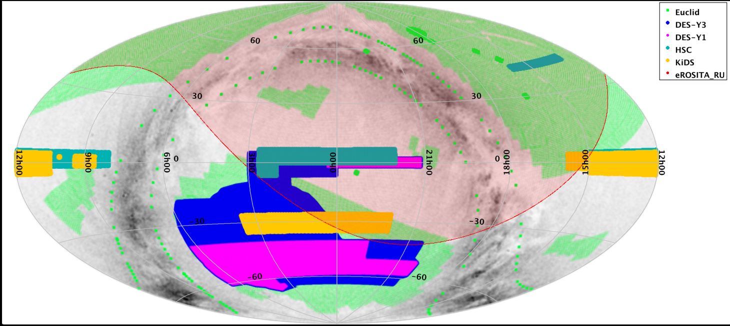
eRASS1



eRASS1


Coma Cluster
Sco X-1
Virgo Cluster
Shapley Supercluster
Cygnus Superbubble
Cyg X-1
eROSITA
Centaurus Cluster
Cas A
Crab Pulsar
North Polar Spur
G156.2+05.7 SNR
Perseus Cluster
Cyg X-2
Cygnus Loop
Large Magellanic Cloud
Fornax Cluster
Vela SNR
Orion Nebula
IKI
SRG/eROSITA 0.3-2.3 keV - RGB Map
MPE

- Optical Data through richness vs. mass scaling relations
- X-ray observations through hydrostatic eql. assumption
- Weak Lensing (DES, KIDS, and HSC)



Credit: F. Pacaud