The fraction of AGNs detected in clusters from deep and wide-field X-Ray surveys

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Motivation

- Clusters are extreme environments where several processes (RPS, mergers, tidal interactions) affect galaxy evolution.
- AGN activity traces mass accretion onto SMBH and is highly influenced by the host galaxy's environment.
- X-rays efficiently identify AGNs because they directly trace SMBH accretion and are less contaminated by emission from the host galaxy's stellar population.
- Several studies suggest that AGN activity is suppressed in cluster cores and enhanced in the outskirts.
- The relative importance of the mechanisms driving this radial dependence remains uncertain.

Aim of this work

Dependence of AGN activity on:

- **Cluster-centric distance:** $0.5R_{500} \le R \le 5R_{500}$
- **Cluster mass:** low- and high-mass systems separated at $M_{500} = 1.5 \times 10^{14}\,M_\odot$
- **Redshift:** $0.07 \le z \le 0.7$ (XCLASS) $0.07 \le z \le 0.25$ (eRASS1)
- **Survey selection:** deep, broad-band XCLASS observations and homogeneous, wide-field eRASS1 coverage.

Using complementary datasets:

- **XCLASS:** deep X-ray observations with non-uniform sky coverage
- **eRASS1:** homogeneous all-sky X-ray coverage, primarily probing lower-redshift clusters
- **WHL12:** optical SDSS cluster data used to derive galaxy-density normalization profiles

Methodology

Cluster sample
X-ray sources selected within $5R_{500}$

XCLASS sample
380 clusters
$0.07 \le z \le 0.7$

eRASS1 sample
3135 clusters
$0.07 \le z \le 0.25$

Assign sources to concentric R_{500} annuli
Exclude central $0\text{–}0.5R_{500}$ region

XCLASS
Non-uniform XMM coverage
Monte Carlo area correction
Cluster-specific $F_{\rm lim}$

eRASS1
Wide-field survey
Mock-cluster background
Uniform flux selection

XCLASS background
Ring area + $\log N$–$\log S$

Background subtraction
+ effective-area correction

eRASS1 background
Mock positions + source counts

Compute AGN surface density in each radial bin

Normalize by WHL12 galaxy density profile

AGN-to-galaxy fraction

XCLASS 83 (Obs.ID. 0782650101)

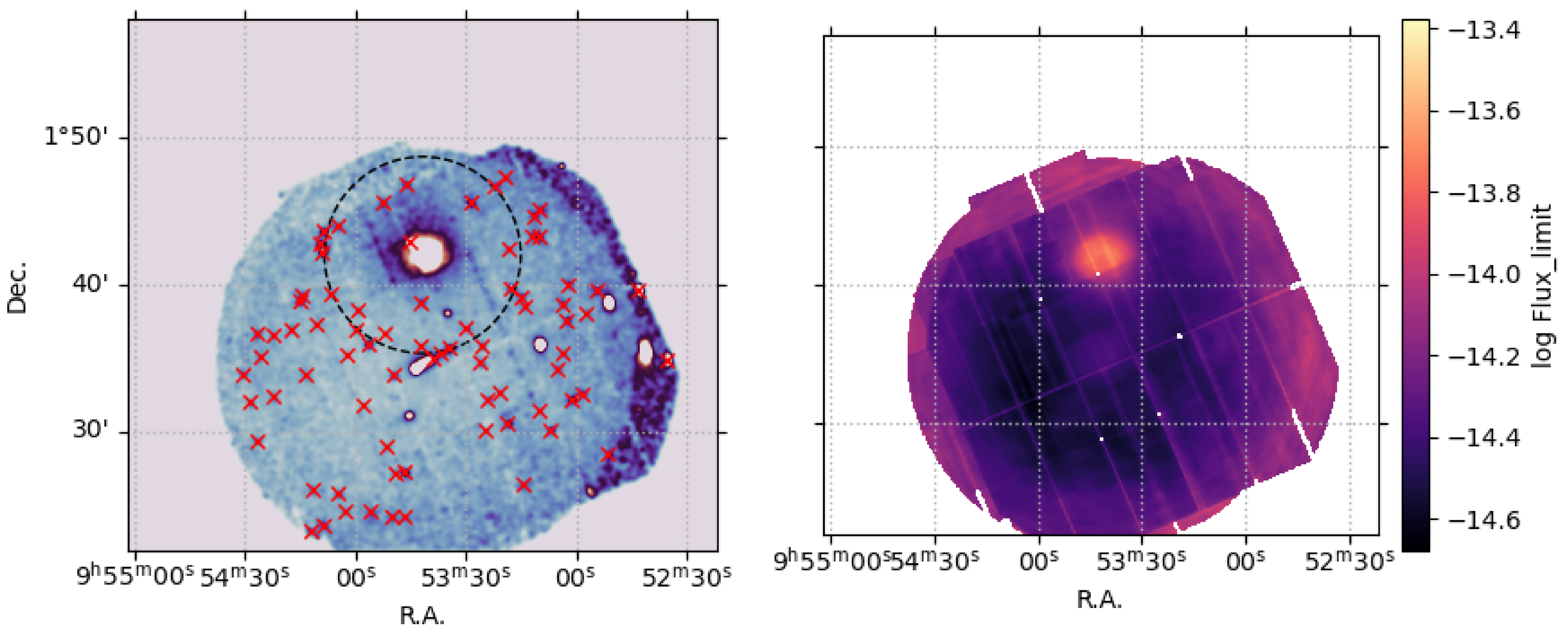

Figure 1: Spatial sensitivity. XMM-Newton observation and sensitivity map with X-ray sources.

XCLASS coverage and sensitivity

XCLASS consists of targeted XMM-Newton observations with non-uniform sky coverage, exposure depth, and flux sensitivity. Each cluster, therefore, requires an individual radial coverage correction, a cluster-specific flux limit from its sensitivity map, and a background estimate for each radial bin, based on the observed area and an assumed $\log N$–$\log S$ relation.

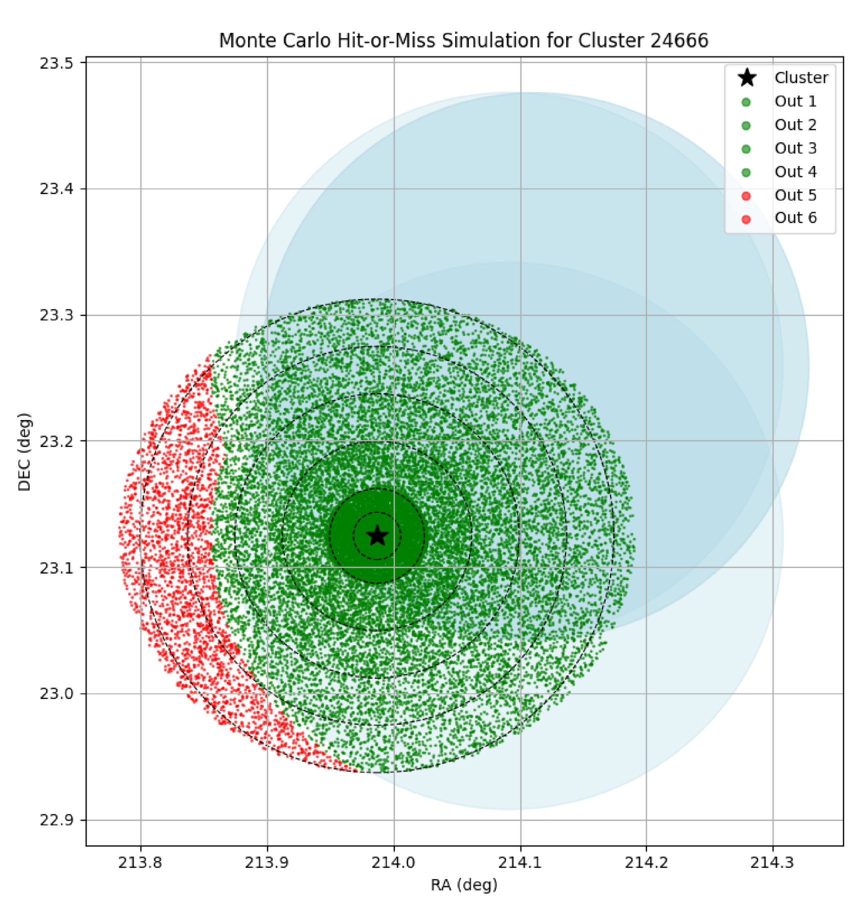

Figure 2: Coverage correction. Monte Carlo sampling estimates the fraction of each R_{500} annulus effectively observed and is used to correct incomplete radial coverage.

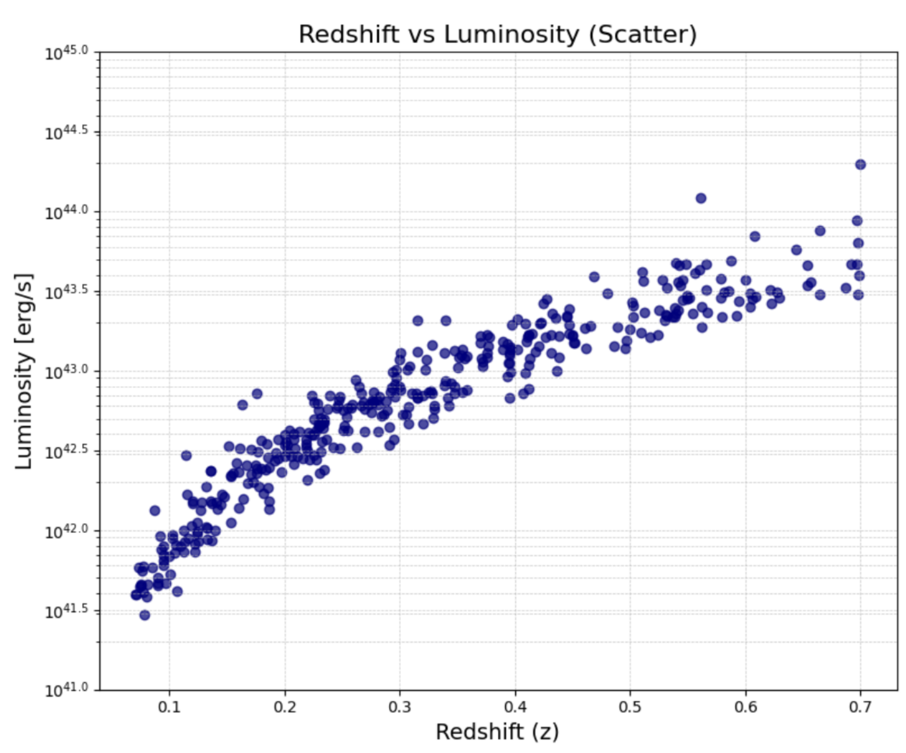

Figure 3: Luminosity. Cluster-specific flux limits are converted to luminosity limits, allowing redshift-dependent luminosity completed subsamples to be defined.

Redshift bin	Luminosity cut	$N_{\rm cl}$
$0.0 < z \le 0.2$	3×10^{42} erg s^{-1}	104
$0.2 < z \le 0.5$	3×10^{43} erg s^{-1}	208
$0.5 < z \le 0.7$	10^{44} erg s^{-1}	73

XCLASS results

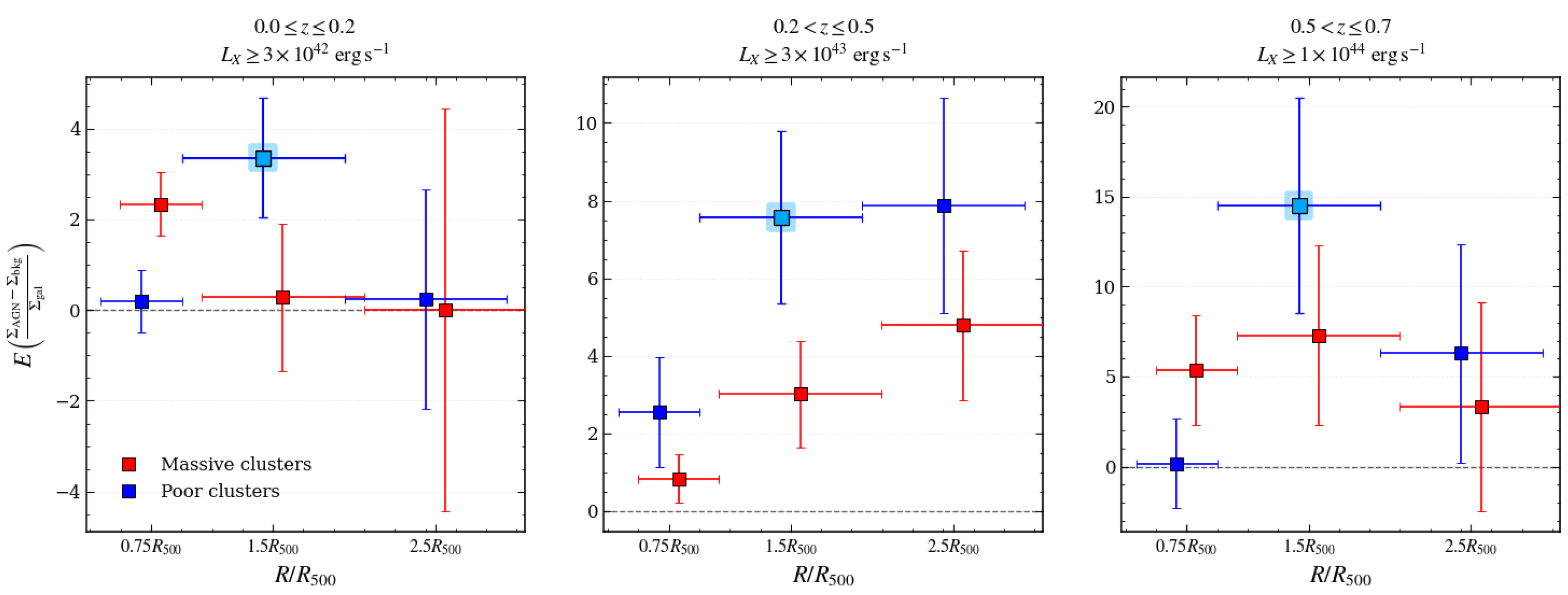

Figure 4: Radial AGN-to-galaxy excess in XCLASS clusters across three redshift bins.

$$E(R) = \frac{\sum_i \frac{N_{{\rm src},i}(R) - N_{{\rm back},i}(R)}{A_{{\rm obs},i}(R)}}{\Sigma_{\rm gal}(R)}$$

$E(R) > 0$: AGN excess relative to the expected galaxy-normalized background.

Main trends (Figure 4)

Intermediate-radius enhancement: The clearest recurring feature is an enhanced AGN-to-galaxy ratio around $1\text{–}2R_{500}$, particularly in poor clusters.

Mass-dependent behaviour: Poor and massive clusters show clear differences, but the ordering changes with radius and redshift. The results therefore do not indicate a simple monotonic dependence on total cluster mass.

Possible redshift evolution: The AGN excess tends to become larger toward higher redshift, especially for poor clusters, although the uncertainties increase and different luminosity thresholds are adopted in each redshift bin.

XCLASS vs eRASS1

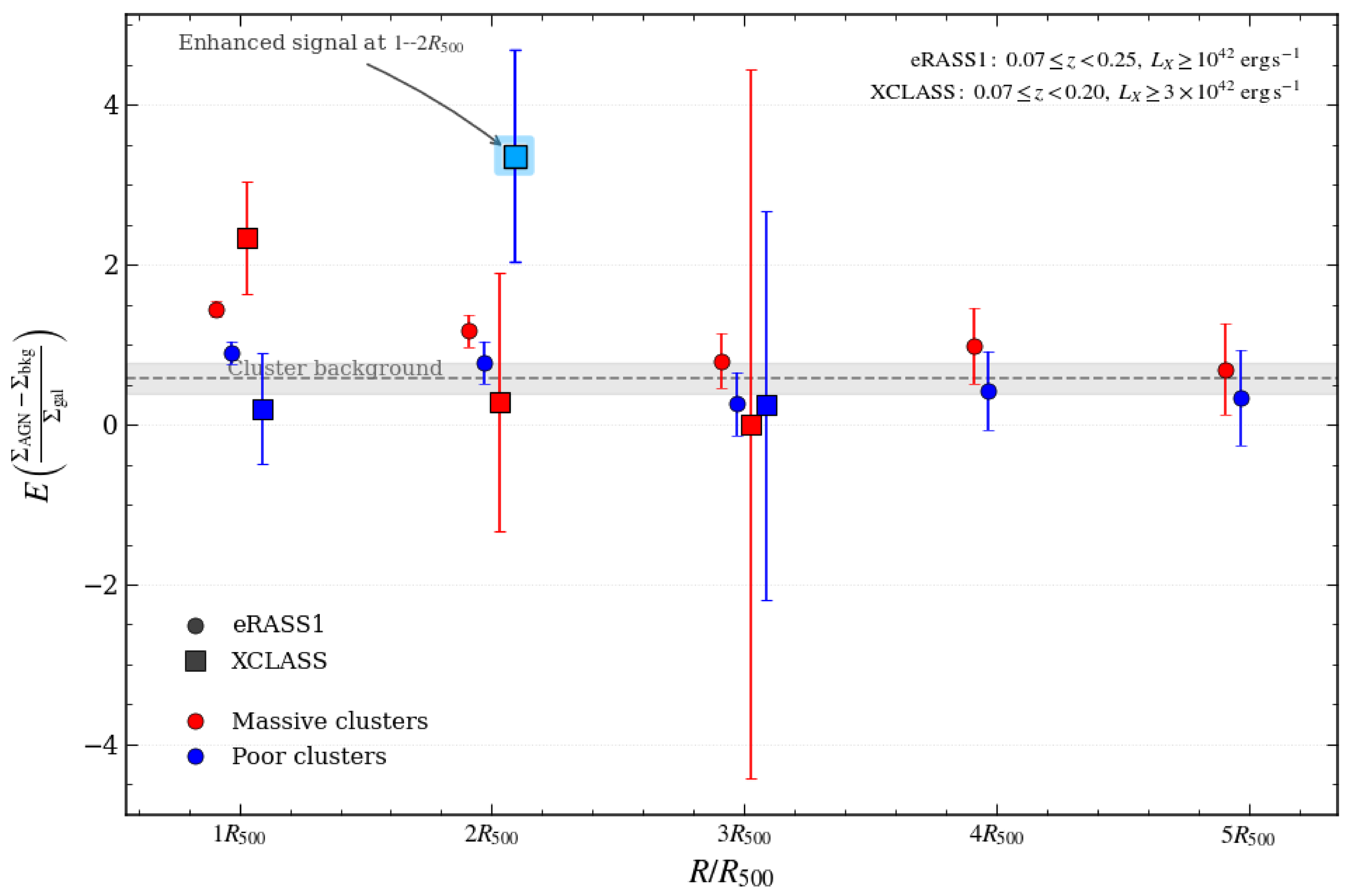

Figure 5: Comparison of the radial AGN-to-galaxy excess measured with XCLASS and eRASS1.

Main comparison (Figure 5)

- **Energy band:** XCLASS includes soft and hard X-rays, while eRASS1 is soft-band selected, increasing potential obscured AGNs.
- **Obscuration:** Obscured AGNs are associated with disturbed/merging hosts, thus driving gas/dust toward the nucleus and triggering and obscuring SMBH accretion.
- **Uncertainties:** Larger XCLASS errors reflect the smaller sample, different exposures, varying sensitivity, and incomplete radial coverage.

Discussion

Physical interpretation

Cluster cores: The dense ICM and strong ram-pressure stripping can remove or heat the cold gas reservoir of cluster galaxies, reducing the fuel available for SMBH accretion and suppressing AGN activity.

Cluster outskirts: Infalling galaxies often undergo interactions and mergers, including within smaller groups prior to cluster infall and these processes can funnel gas toward the nucleus and trigger SMBH accretion.

Higher redshift: Galaxies at earlier cosmic times are typically more gas-rich and undergo more frequent interactions, providing a larger cold-gas supply and potentially increasing the probability of AGN triggering.

Main conclusions

- **AGN activity depends on cluster-centric distance**
  $1 - 2R_{500}$ enhancement corresponds to infall, interactions, and mergers.
- **Cluster mass alone does not control the AGN fraction**
  No simple monotonic dependence on M_{500} is observed, local environmental conditions are more important.
- **Possible increase of AGN activity toward higher z**
  Due to larger gas reservoirs and frequent interactions, although uncertainties remain large.
- **Survey selection is crucial**
  Deep, broad-band surveys detect more obscured AGNs, homogeneous surveys provide cleaner statistics.

References

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