An X-ray Census of AGN in the Virgo and Fornax Clusters of Galaxies with SRG/eROSITA

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First Results from the SRG/eROSITA All-Sky Survey: From Stars to Cosmology, Garching, 2024.9.16

AGN Demography

Two lines of research:

1) Towards greater distances: first-generation AGNs at the early universe

2) Towards larger samples: (all-sky) surveys of AGNs in the low-redshift universe

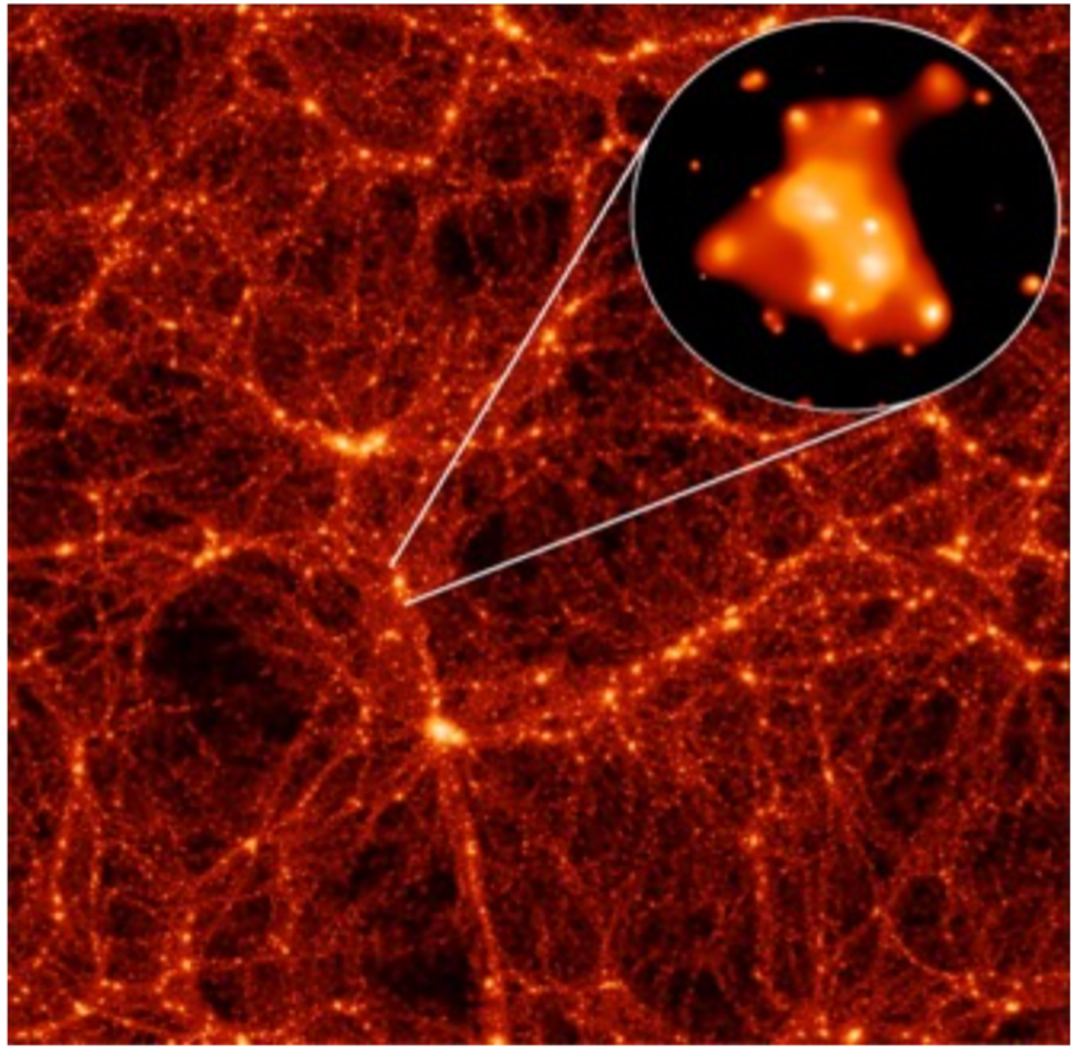
✓ A vastly large number of AGNs lurk at the center of normal and dwarf galaxies

✓ Most of these low-redshift AGNs have low luminosities

- weakly accreting SMBHs fed by a radiatively inefficient, hot accretion flow
- smaller black holes (IMBHs) accreting at a rate closer to the Eddington limit

Environmental Effects on galaxies and AGNs

Cluster of Galaxies: the largest gravitationally-bound system in the hierarchical universe



★ Environmental effects to galaxy evolution

- *gravitational effects*:
  tidal interactions
  harassment
  → **Stellar redistribution**

- *hydrodynamic effects*:
  ram-pressure
  thermal conduction
  starvation
  → **Gas stripping**

- quench star formation
- suppress (or temporarily trigger) SMBH accretion

Chandra X-ray Surveys of nearby AGNs

X-rays provide direct evidence for AGNs, which trace the hot plasma in and around the accretion flow onto the SMBH

Cluster of galaxies:

AMUSE-Virgo (Gallo et al. 2008)

Fornax (Lee et al. 2019)

Antlia (Hu et al. 2023)

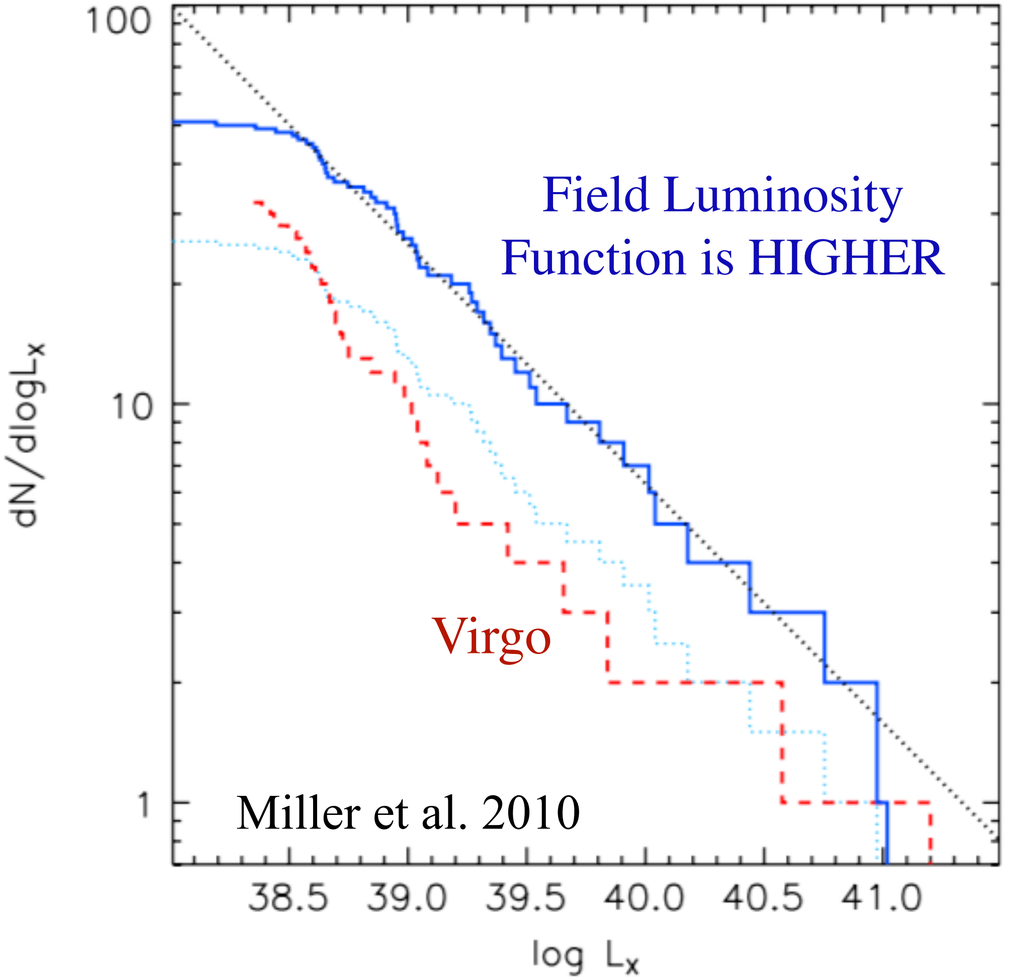
- X-ray occupation fraction of 20% − 30%

Field galaxies:

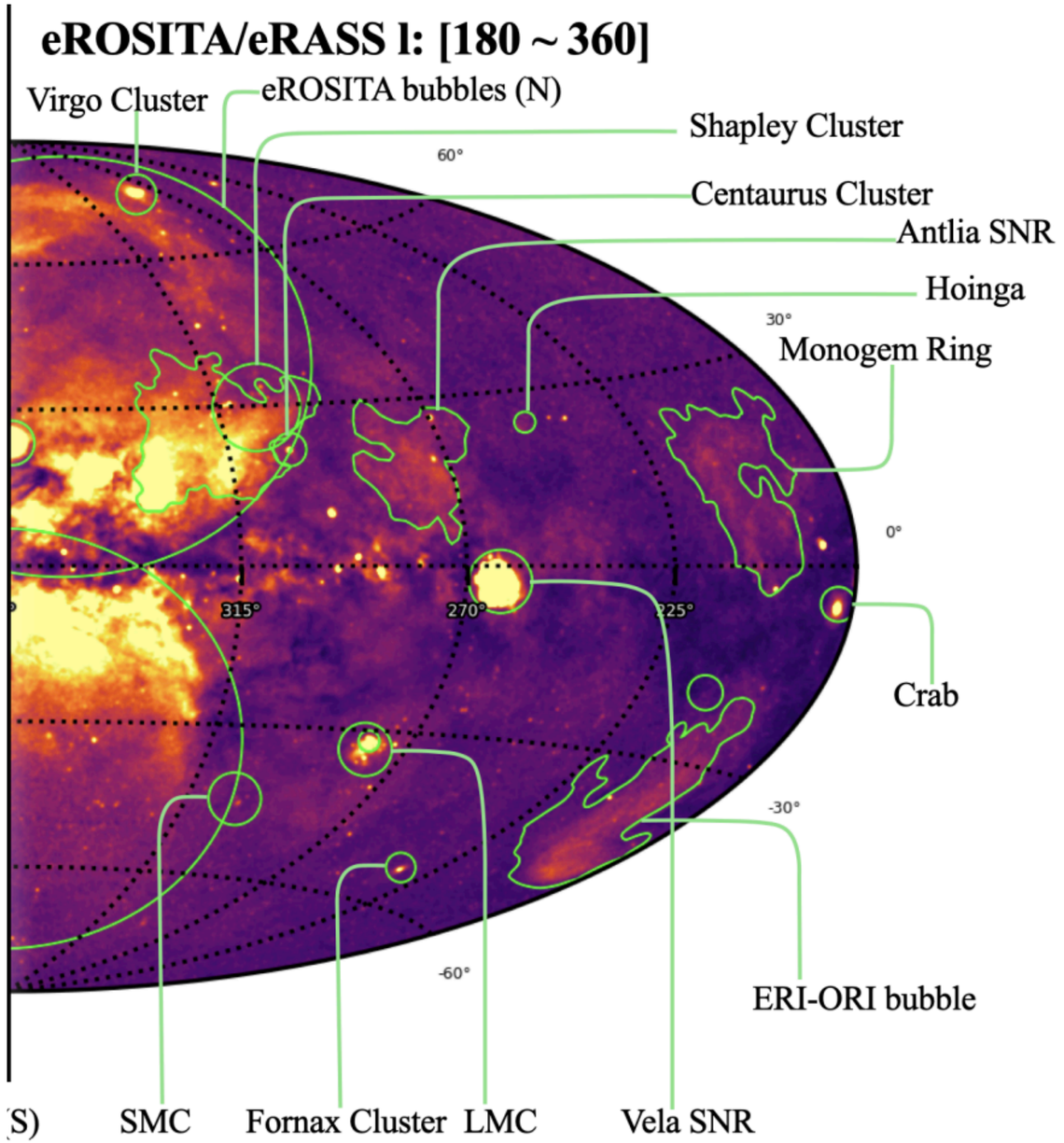
AMUSE-Field (Miller et al. 2010)

Survey of Nearby Galaxies (She et al. 2017, Bi et al. 2020)

- Higher X-ray occupation fraction of ~ 45% − 50%



SRG/eROSITA All-sky Survey (eRASS)



Zheng et al. 2023

energy range: 0.2 - 10 keV

half-energy width [HEW]: ~ 30”

sensitivity: ~ 10^{-14} erg s^{-1} cm^{-2}

(~ 10^{39} erg/s at Virgo/Fornax distances)

- **Allowing for a full X-ray census of Virgo and Fornax member galaxies**

Cluster Member Galaxies

Virgo

Extended Virgo Cluster Catalog (EVCC; Kim et al. 2014)

- 1589 spectroscopically identified galaxies
- 3.5 times the virial radius ($R_{200} \approx 1.0$ Mpc)
- 50% completeness level for galaxies with r-band magnitude ~ 16.5 mag ($\lesssim 10^8$ $M_\odot$)

Fornax

Fornax Cluster Catalog (FCC; Ferguson 1989)

- 340 photography-based likely members
- ~ 1.5 times the virial radius ($R_{200} \approx 0.7$ Mpc)
- completeness limit of $B_T \sim 18$ mag ($\sim 10^8$ $M_\odot$)

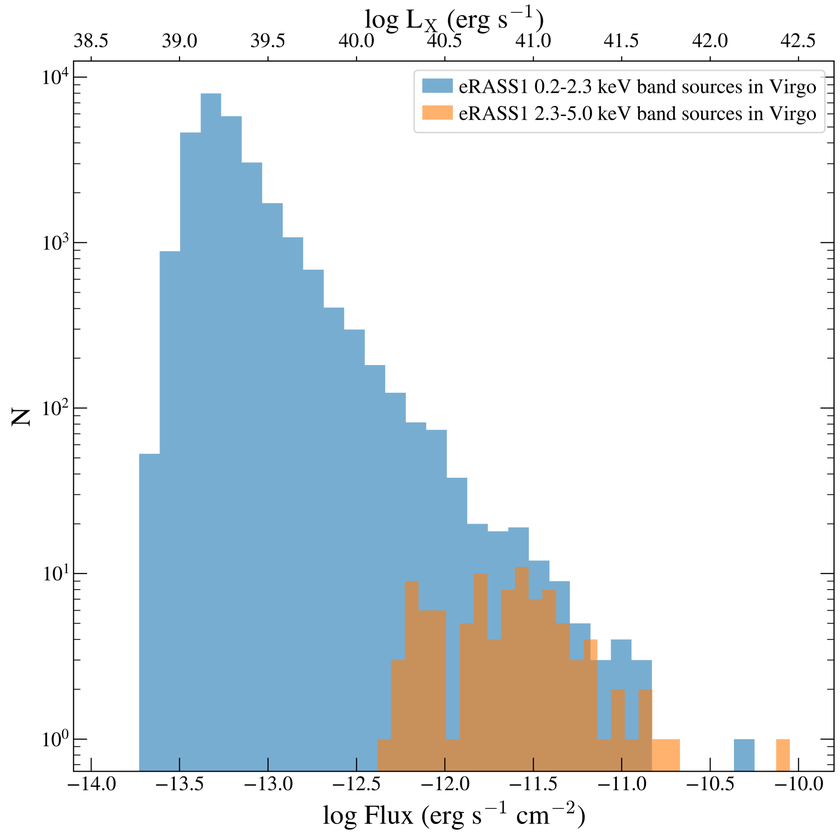
Nuclear X-ray Sources Identification

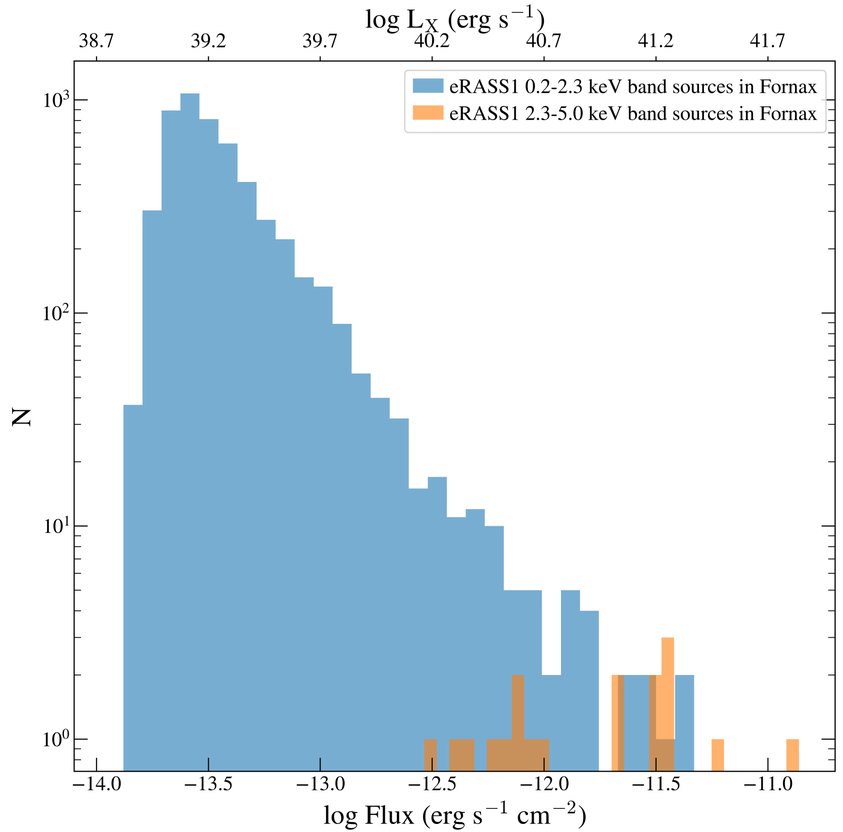
<u>All-sky survey X-ray source catalogs from eRASS1</u> (Merloni et al. 2024):

soft-band (0.2–2.3 keV) & hard-band (2.3–5 keV) catalog

- Virgo: 50 nuclear sources, $L_{X,\,0.2-2.3}$: $9.2 \times 10^{38} - 3.1 \times 10^{41}$ erg s^{-1}
- Fornax: 10 nuclear sources, $L_{X,\,0.2-2.3}$: $9.6 \times 10^{38} - 2.1 \times 10^{41}$ erg s^{-1}

(matching radius: 10”, random match ~ 2%)





soft-band completeness limit ~ 10^{39} erg/s

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The paucity of luminous AGNs!

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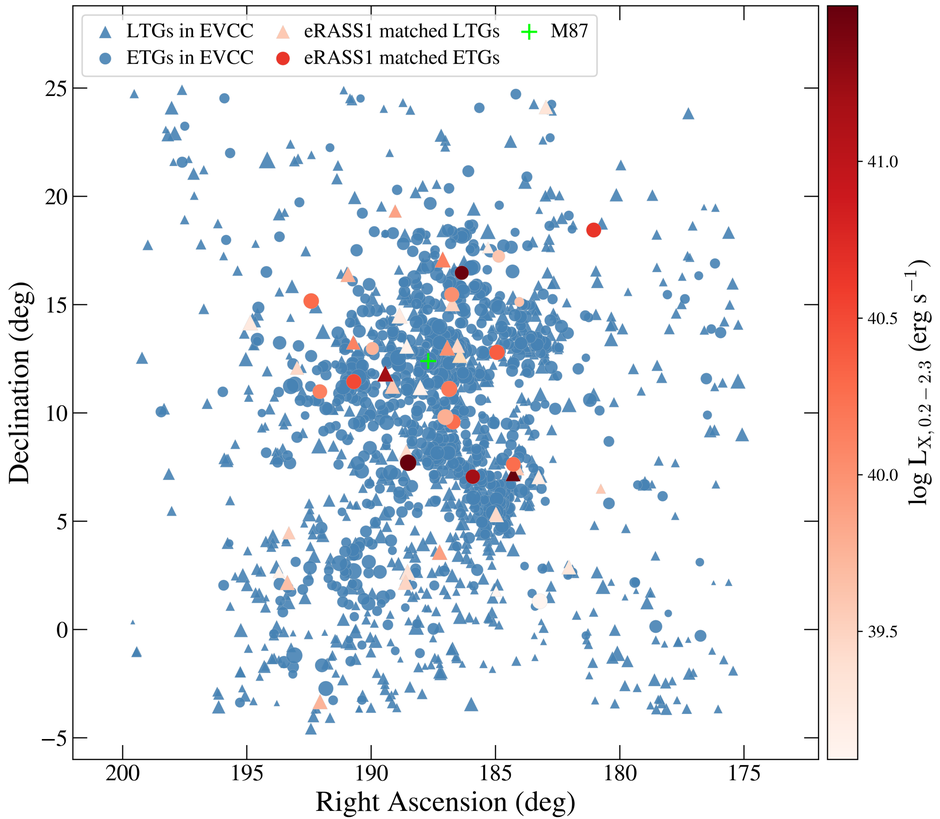

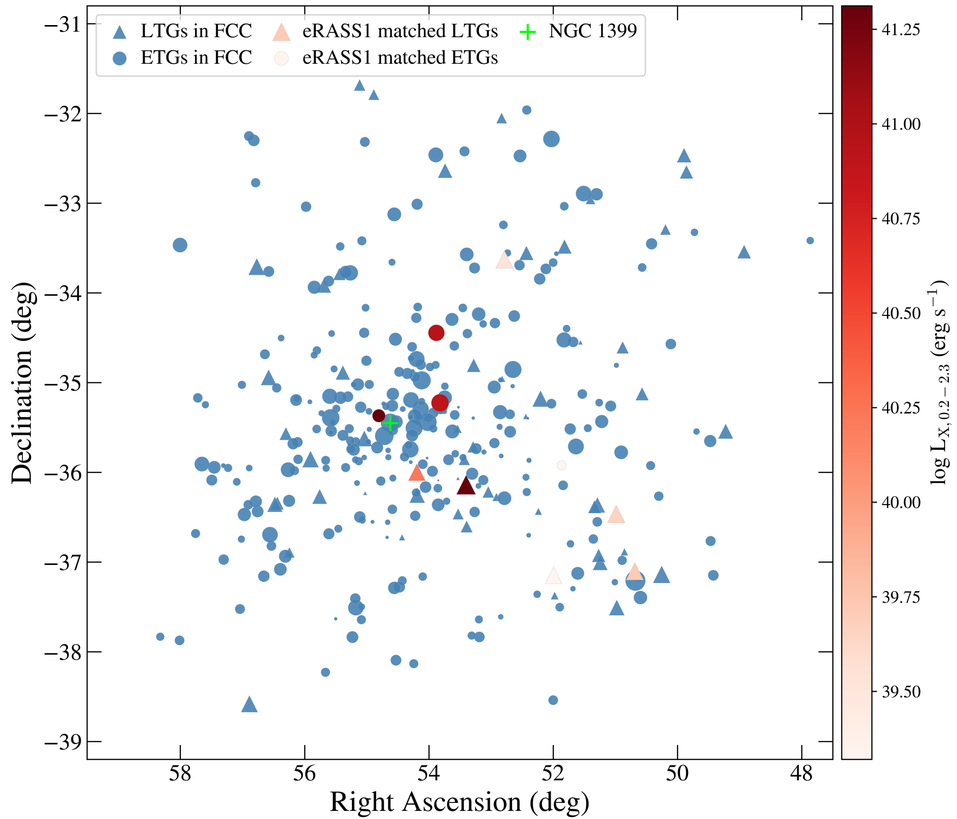

Host Galaxy Contamination

- Low-mass X-ray binaries

  $L_{(0.2-2.3\ \mathrm{keV})} \approx 7.9 \times 10^{38}\ \mathrm{erg\ s^{-1}}\ (M_*/10^{10} M_\odot)$

  ➡ statistically only a small contribution

- Star forming activity (high-mass X-ray binaries and/or diffuse hot gas)

  $L_{(0.2-2.3\ \mathrm{keV})} \approx 5.6 \times 10^{39}\ \mathrm{erg\ s^{-1}}\ (\mathrm{SFR}/\mathrm{M_\odot\ yr^{-1}})$

  estimate SFR from WISE W3-band image

  only two Virgo galaxies and three Fornax galaxies have sufficient SFR to explain the observed nuclear X-ray emission

  ➡ statistically minor contribution

Comparison with Chandra Surveys

★ **AMUSE-Virgo (ETGs), *Gallo et al. (2010)*:**

- 32 nuclear X-ray sources out of 100 ETGs in Virgo
- 3 eRASS1 detections in common, 2 (EVCC 626, 884) new matches
- difference in sensitivity (Chandra: ~ 10^{38} erg/s)
- Note: for M87, eRASS1 has no detection due to the heavy diffuse hot gas

★ **Virgo LTGs, *Soira et al. (2022)*:**

- 35 nuclear X-ray sources out of 75 LTGs in Virgo
- 13 eRASS1 detections in common, 1 new match

★ **Fornax ETGs, *Lee et al. (2019)*:**

- 11 nuclear X-ray sources out of 29 ETGs in Fornax, all have Lx < 2 x 10^{39} erg/s
- only 1 eRASS1 detection in common, 1 new match

AGN Occupation Fraction

Occupation fraction of an X-ray AGN: $f_{occ} = N_{AGN} / N_{galaxy}$

- Virgo: 50/1589 ≈ 3.1% ± 0.4% [for $\log(M_*/M_\odot) > 7.8$: 50/1203 ≈ 4.2 ± 0.6%]
- Fornax: 10/340 ≈ 2.9% ± 0.9%

Subsets for Virgo member galaxies

Group	Stellar mass	Projected radius	Morphology
$7.8 \leq \log M_* \leq 8.65$	4/602 (0.7±0.3%)	-	-
$\log M_* > 8.65$	46/601 (7.7±1.1%)	-	-
$R < 1.68$ Mpc	-	28/795 (3.6±0.7%)	-
$R > 1.68$ Mpc	-	22/794 (2.6±0.6%)	-
ETG	-	-	17/774 (2.2±0.5%)
LTG	-	-	33/815 (4.0±0.7%)

Overall, the occupation fraction are much lower than that found in nearby non-cluster galaxies (at least > 10%)

SUMMARY

- ⋆ An unbiased survey of X-ray AGNs in Virgo ans Fornax Clusters using the first all-sky scan of eROSITA.
- ⋆ A large fraction of genuine AGNs are identified for the first time.
- ⋆ Low AGN occupation fraction (~ 3%) for both clusters compared to field galaxies, suggesting the suppression of AGN activity in the cluster environment.
- ⋆ nuclear X-ray sources in dwarf galaxies ($M_* \lesssim 10^9$ $M_\odot$)
  nuclear X-ray sources with variability

More details in Hou, Hu & Li 2024, ApJ, 965, L24