AXES-2MRS: A new all-sky catalogue of extended X-ray galaxy groups

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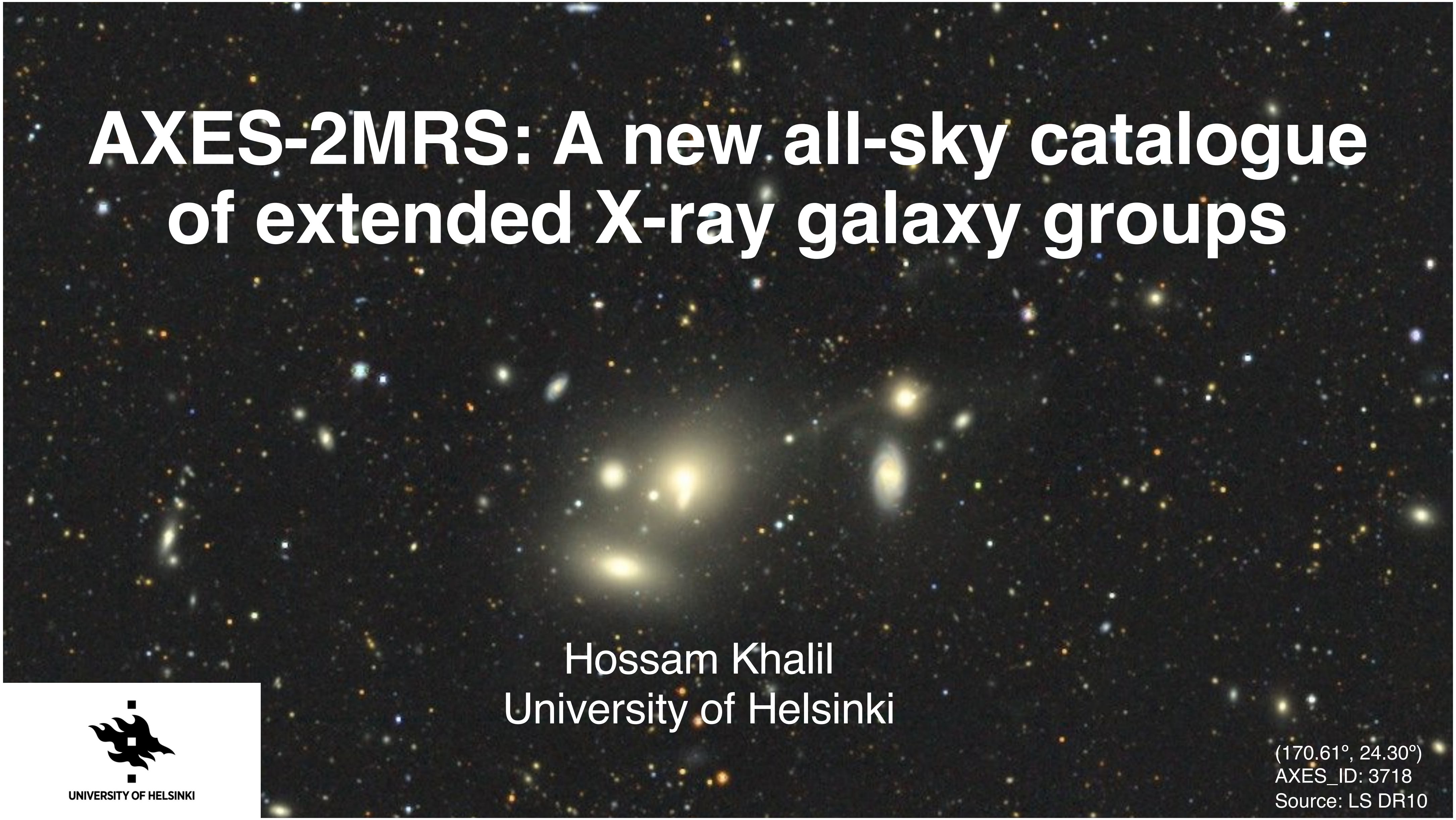

(170.61°, 24.30°)
AXES_ID: 3718
Source: LS DR10

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Outline

- Galaxy clusters/groups as cosmological probes
- AXES-2MRS
  - AXES: a new catalogue of X-ray sources from RASS
  - 2MRS: optical group catalogue used for identification
  - AXES-2MRS in the redshift – luminosity space
- XMM-Newton subsample
  - X-ray temperatures (kT), masses (M), luminosities (L_X), surface brightness profiles, velocity dispersion (σ_v), and halo concentration (c)
- Scaling relations: σ_v-L_X, σ_v-kT, kT-L_X, σ_v-M, and c-L_X
- Summary & discussion

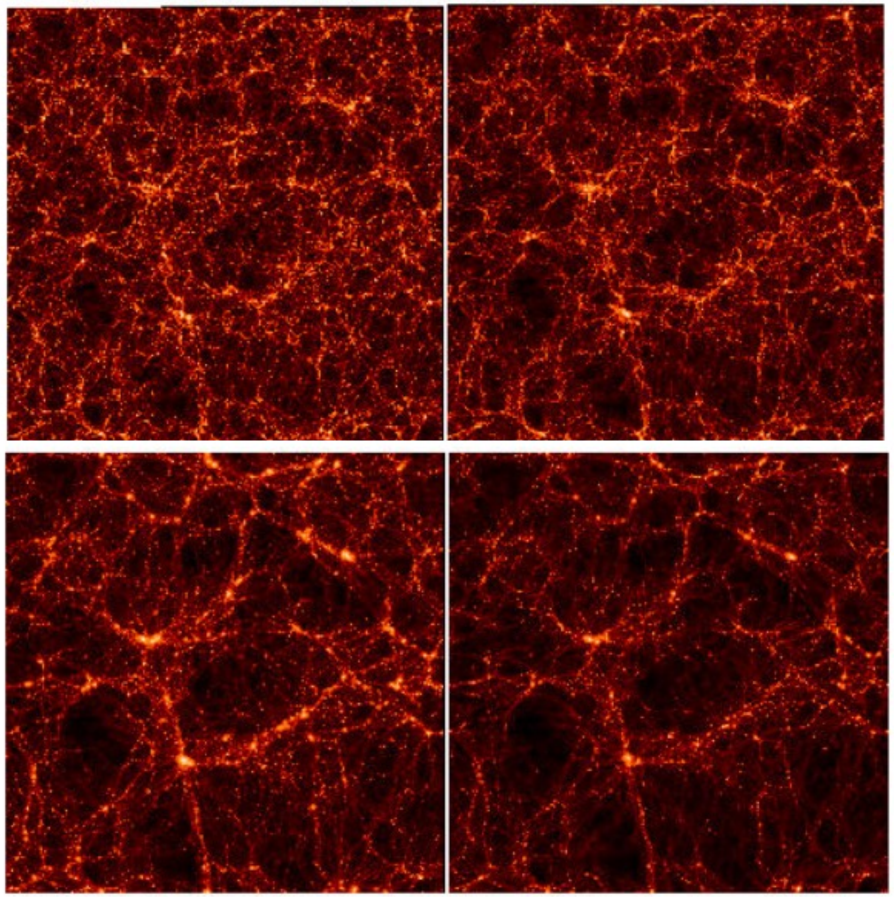
(86.37°, -25.94°)
AXES_ID: 2009
Source: LS DR10

Galaxy clusters/groups as cosmological probes

- Large scale structure (LSS) can be used for testing cosmological models through:
  - Galaxy distribution
  - Gravitational lensing by the LSS
  - Galaxy clusters/groups

SCDM
$\Omega_m = 1$

τCDM
$\Omega_m = 1$



λCDM
$\Omega_m = 0.3$
$\Omega_\lambda = 0.7$

OCDM
$\Omega_m = 0.3$

Virgo simulations: Jenkins et al, 1998 Astophysical Journal,499,20-40

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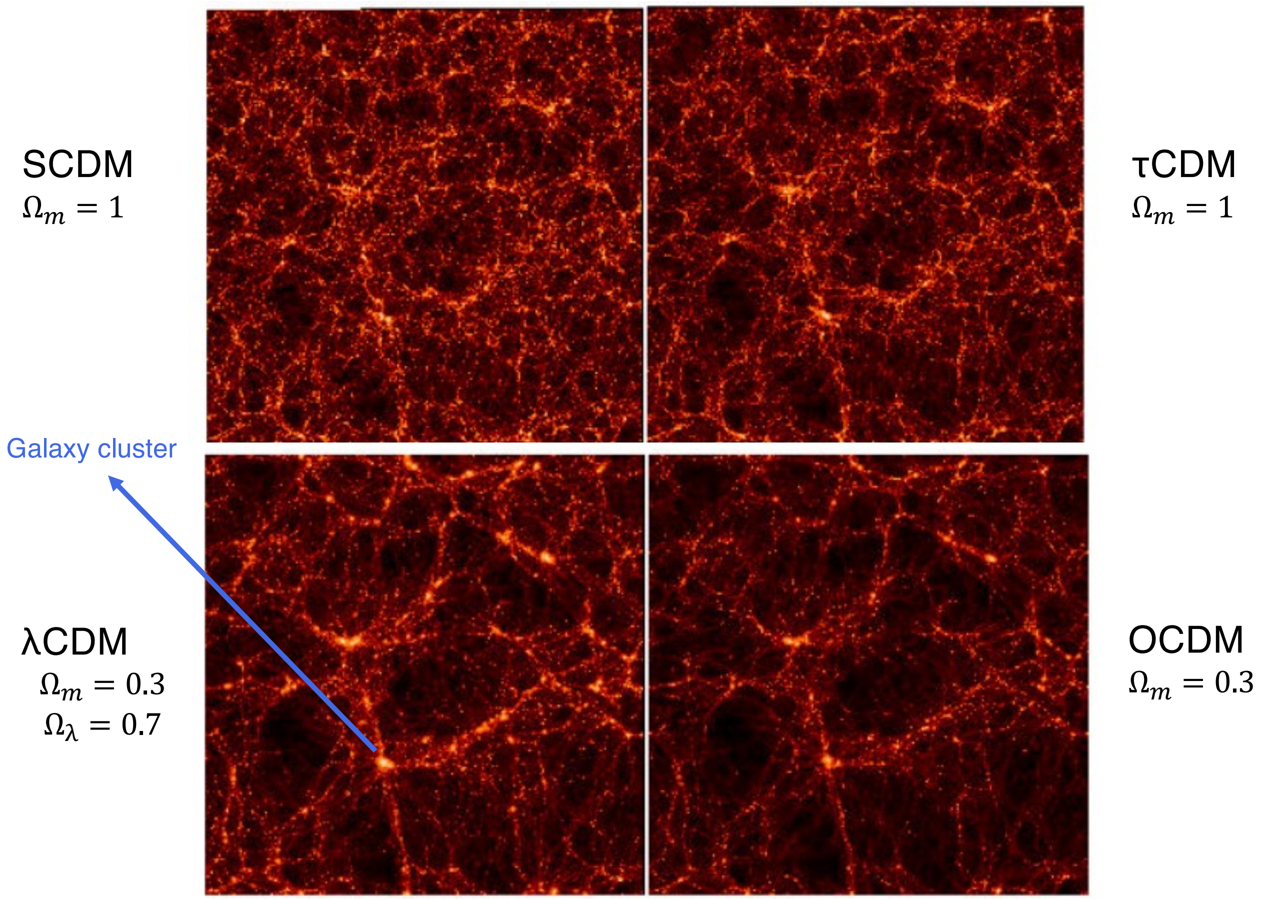

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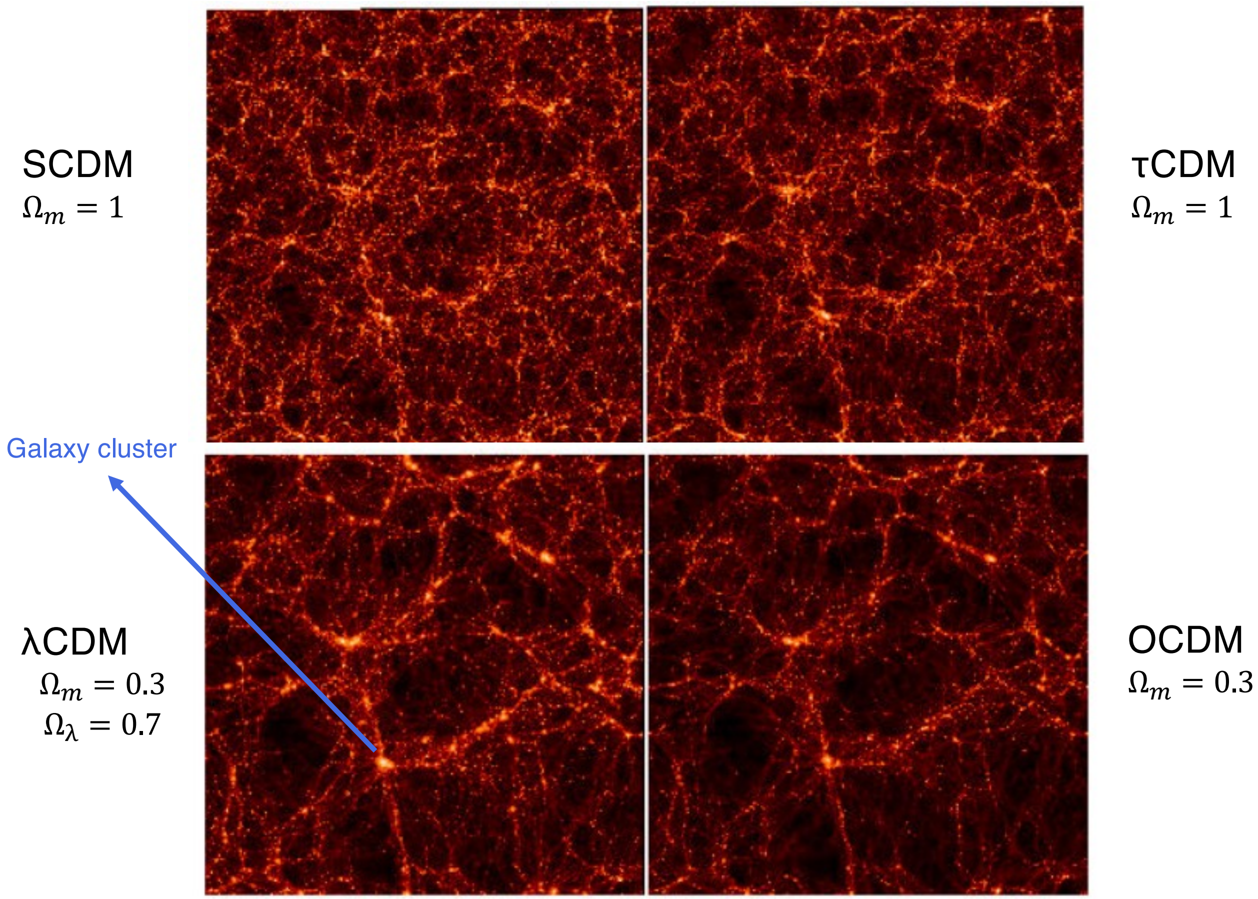
- Cluster abundance *(dn/dM)* is used to constrain the present-day matter density parameter Ω_m, and the amplitude of the mass fluctuations σ_8

- Observable mass proxies: X-ray temperature, X-ray luminosity, intracluster medium gas mass, velocity dispersion, etc.



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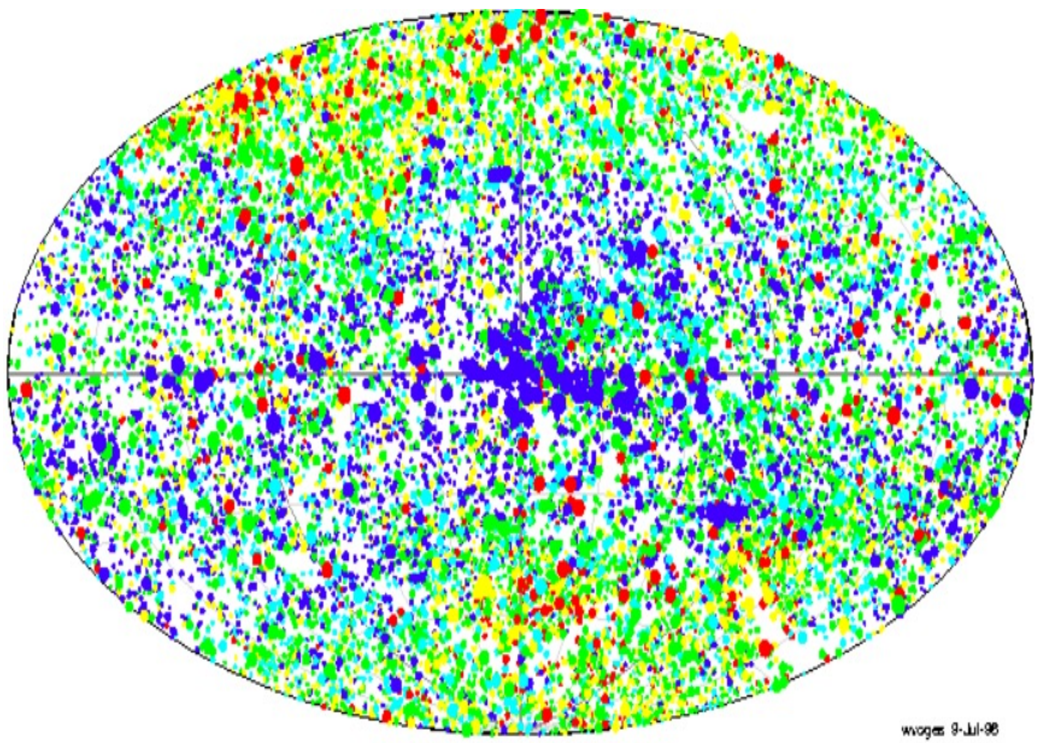
AXES-2MRS

AXES: a new catalogue of X-ray sources from RASS

- ROSAT All-Sky Survey (RASS) detected over 100,000 X-ray sources on different scales
- RASS only cares about the emission not the source
- Extragalactic contamination e.g., AGNs, quasars, M dwarfs. Galactic sources: M dwarfs, SNRs. All point sources except SNRs.

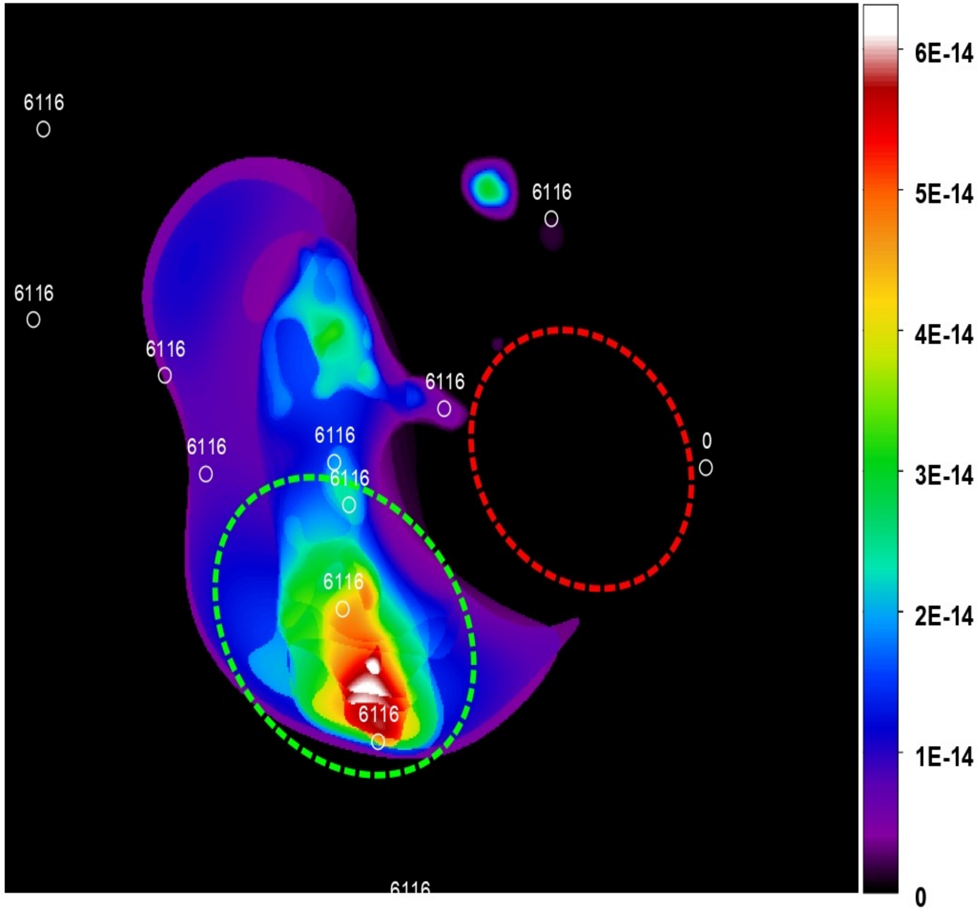


RASS bright sources (~20,000) from W. Voges et al. (1996)

AXES-2MRS

AXES: a new catalogue of X-ray sources from RASS

- A new X-ray extended source catalogue (AXES) was created using 0.5-2.0 keV band images and angular sizes of 12-24' (removing emission detected at less than 6')
- AXES has over 6,000 extended sources.
- X-ray emission detected is only 2D, so we need a third dimension for source identification?



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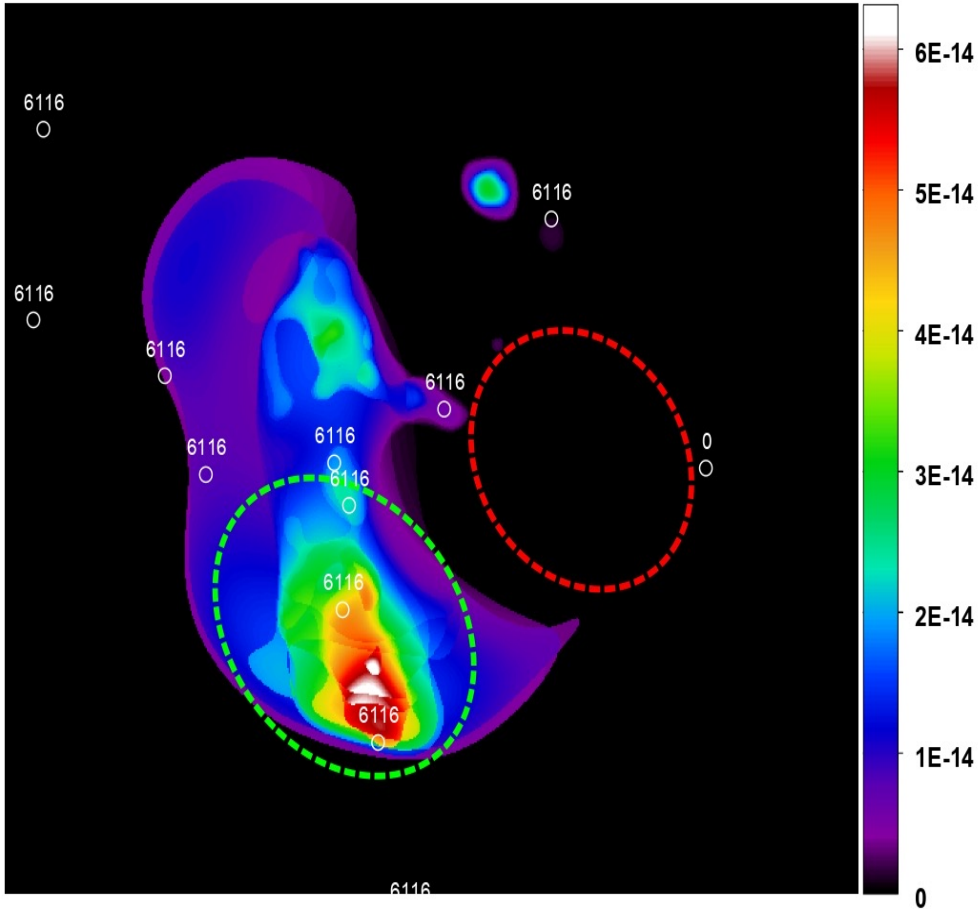
    - Redshift → spectroscopy

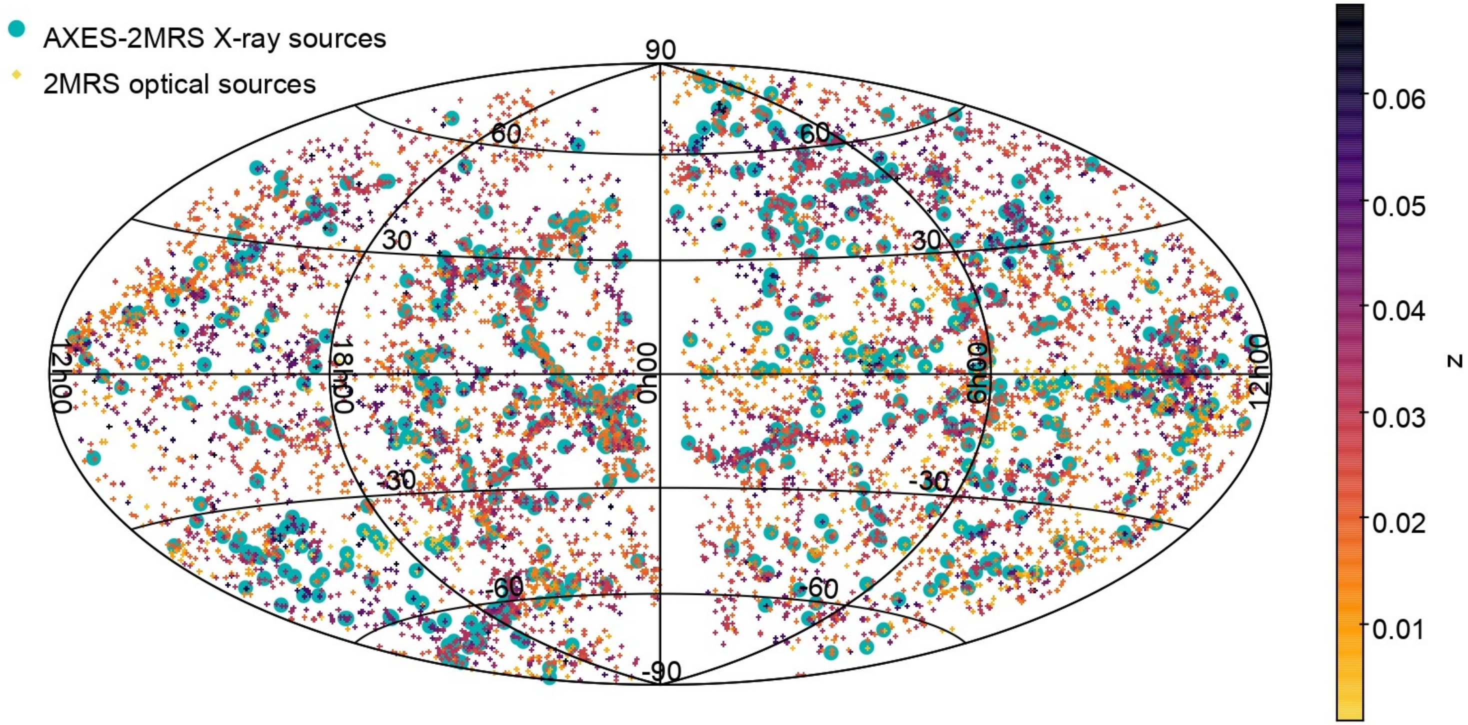


AXES-2MRS

2MRS: optical group catalogue used for identification (Tempel et al. 2018)

- Enters 2MRS: an optical group catalogue based on the 2MASS spectroscopic survey. It adopts a probabilistic Bayesian approach which detects the clustering pattern using observational parameters

- A total of 558 galaxy groups was identified (down to 3 members) producing AXES-2MRS

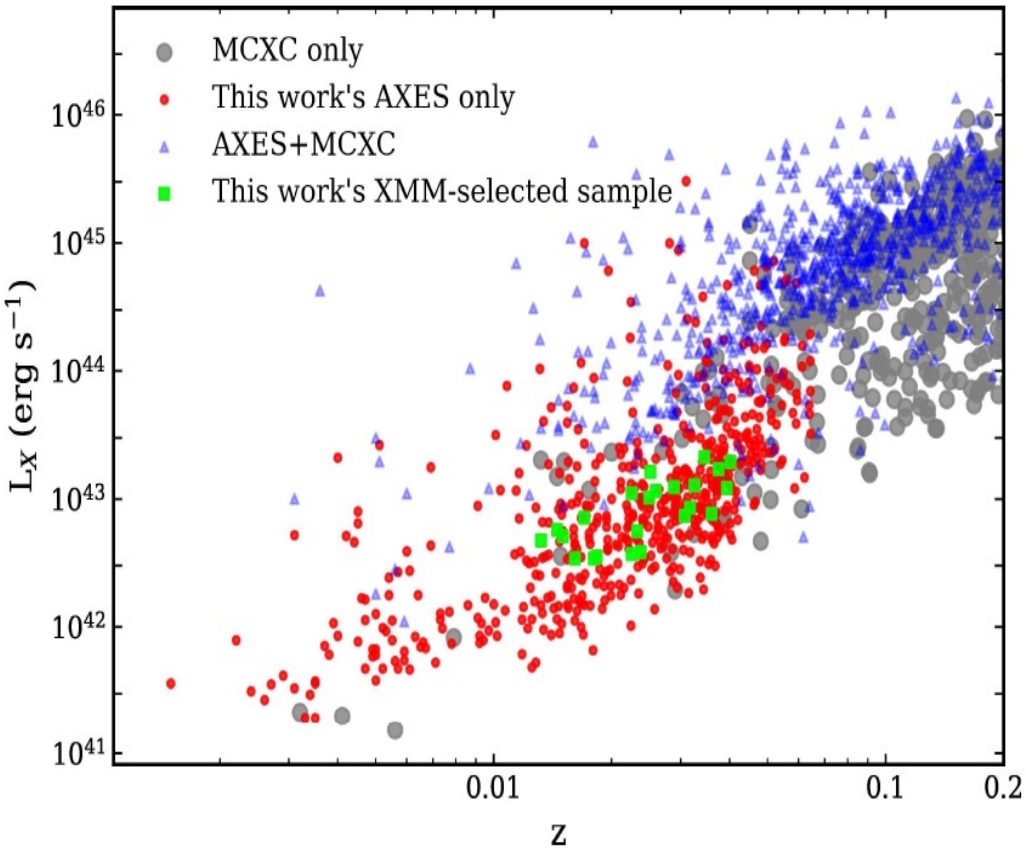


AXES-2MRS

AXES-2MRS in the redshift- luminosity space

- MCXC is a large X-ray cluster catalogue compiled from different smaller catalogues. It has 1743 systems

- AXES-2MRS improves the completeness of X-ray catalogues below 10^{44} erg/s



XMM-Newton Subsample

Redshifts (z) and velocity dispersions (σ_v)

- An XMM-Newton subsample of 25 groups was formed by matching AXES-2MRS with XMM-Newton public data for detailed emission properties
- Median redshifts for the groups
- Velocity dispersion using the gapper estimator

$$\sigma_v = c\left(\frac{\sqrt{\pi}}{N(N-1)}\right)\sum_i^{N-1} w_i g_i,$$
$$w_i = i(N-i), g_i = z_{i+1} - z_i$$

Group ID (#)	RA (J2000)	Dec (J2000)	z_{med}	σ_v (km s^{-1})
361	16.853	32.399	0.016	369.7 ± 82.5
505	21.445	-1.395	0.0171	437.8 ± 76.1
827	35.780	42.986	0.0197	509.5 ± 117.2
859	36.401	36.961	0.0353	480.3 ± 167.0
1571	61.642	30.379	0.0179	370.4 ± 102.7
1830	74.732	-0.484	0.0144	320.3 ± 85.1
2009	86.370	-25.936	0.0388	925.0 ± 200.6
2161	96.162	-37.337	0.0329	568.9 ± 151.1
2533	315.436	-13.311	0.0278	408.8 ± 125.4
2541	117.844	50.202	0.0229	521.1 ± 169.5
2657	125.154	21.072	0.017	373.2 ± 103.5
3551	164.543	1.612	0.0405	339.1 ± 110.3
3718	170.612	24.296	0.027	477.7 ± 166.1
4050	182.018	25.239	0.023	318.9 ± 97.8
4808	202.351	11.765	0.0239	347.1 ± 101.0
5089	210.908	-33.983	0.0139	238.0 ± 66.0
5841	244.338	34.903	0.0303	313.0 ± 96.0
5914	247.417	40.826	0.0318	590.5 ± 110.9
6015	254.498	27.858	0.0345	309.8 ± 107.7
6116	260.202	-1.039	0.0286	537.7 ± 137.2
6407	281.827	-63.332	0.015	470.8 ± 83.4
6666	304.458	-70.819	0.0131	419.8 ± 136.5
6916	316.840	-25.459	0.0359	577.4 ± 200.8
7427	348.942	-2.389	0.0234	473.0 ± 145.1
7727	181.04	20.293	0.0248	445.2 ± 94.0

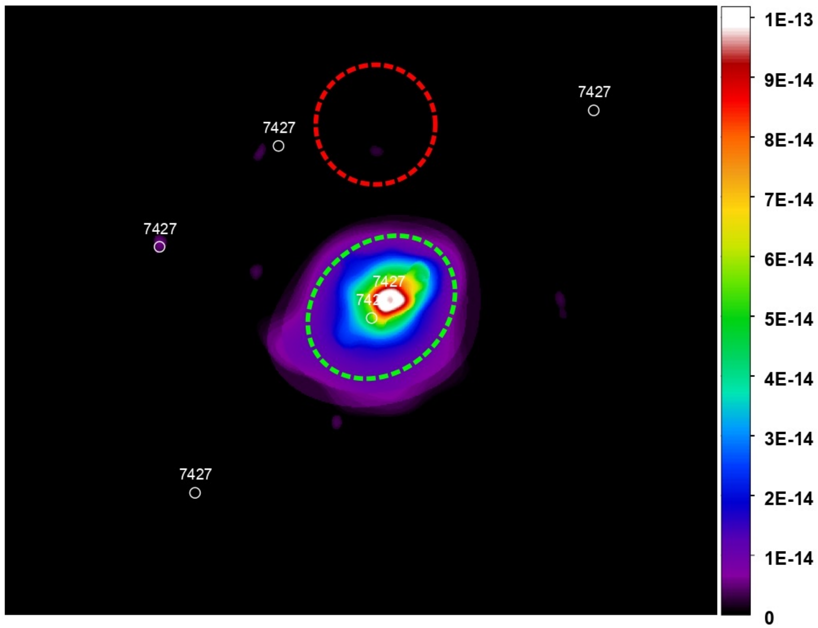
Notes. RA and Dec are coordinates of the emission centres.

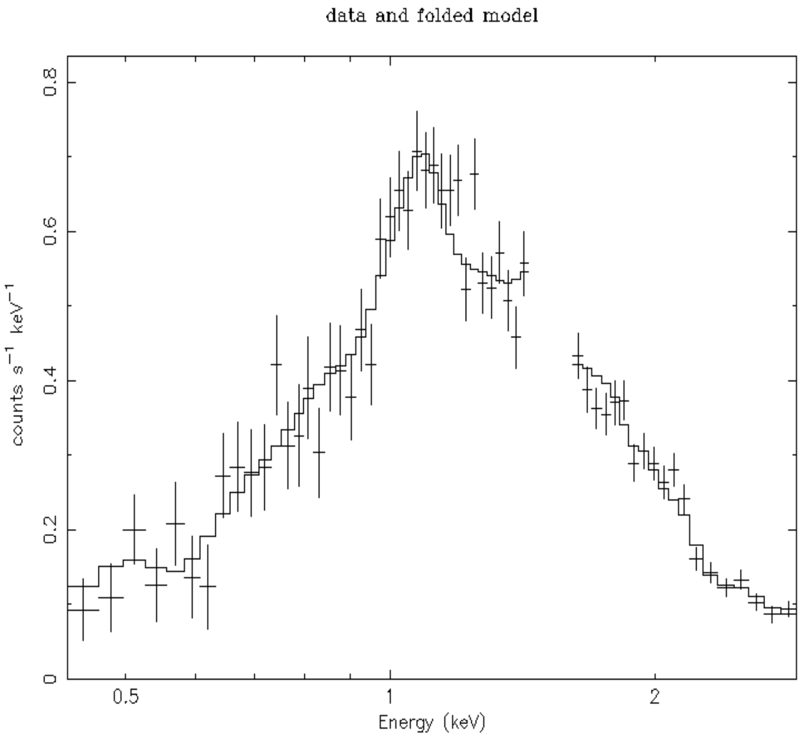
XMM-Newton Subsample

IGrM X-ray temperatures (kT)

APEC: emission spectrum from ionized diffuse gas

- Spectral extraction was done using *SAS* (source & background)
- kT measured by fitting the spectra with absorbed (galactic nH) *APEC* model [z, Z_{metal}, N, nH, kT]





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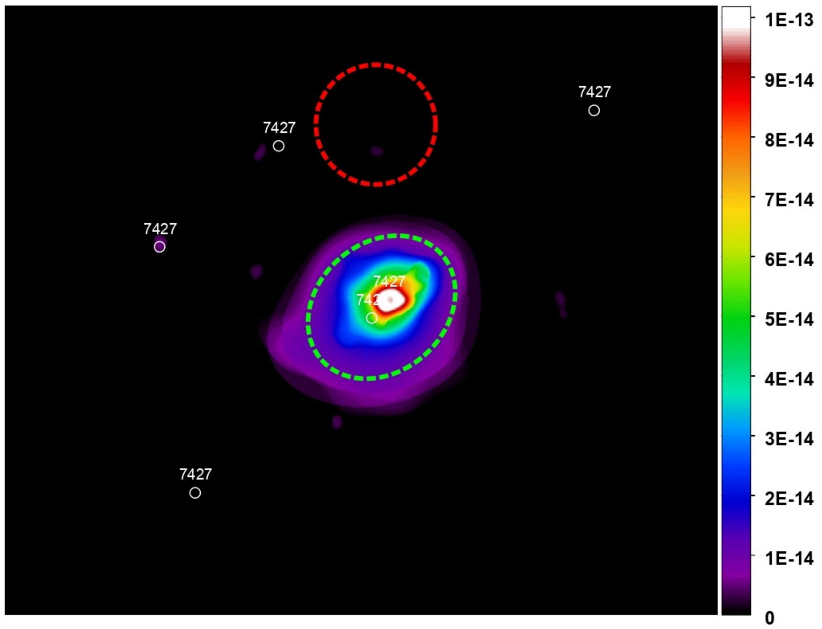
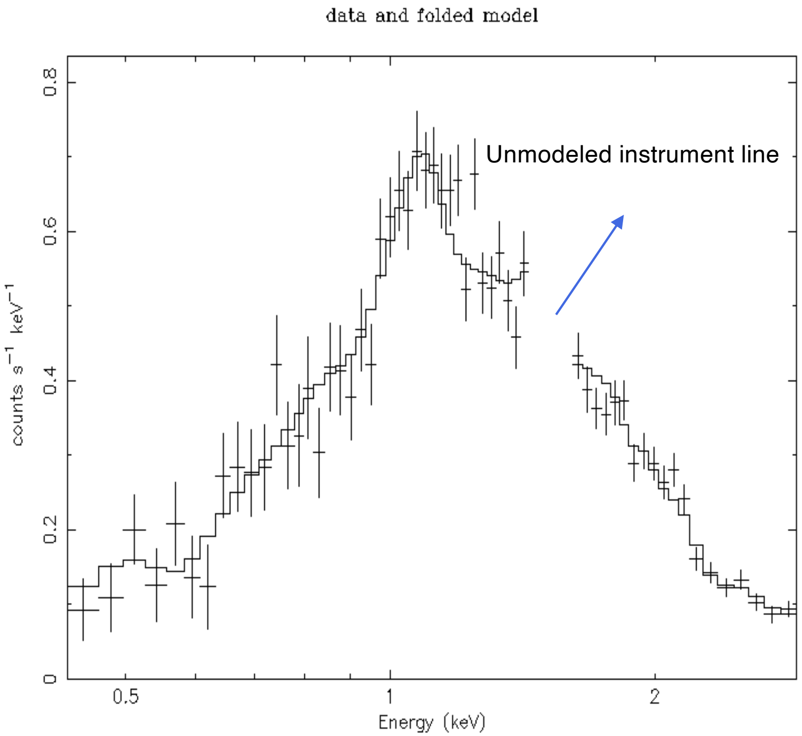




XMM-Newton Subsample

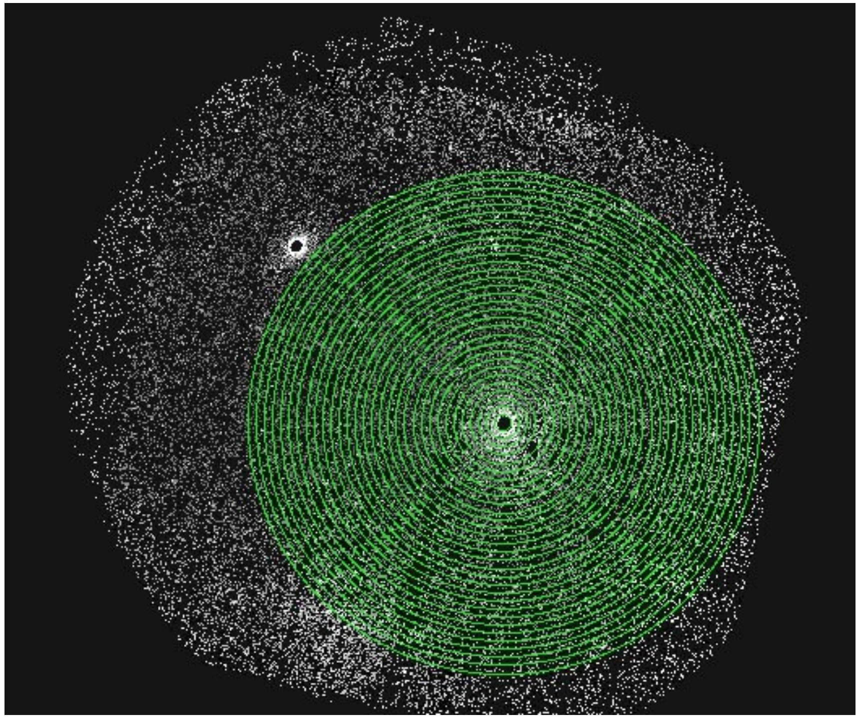
Surface brightness profiles (β)

Luminosity
Flux
Surface brightness

- Surface brightness fitting was done using *a* 1D beta model:

$$\Sigma(r) = \Sigma_0 \left[1 + \left(\frac{r}{r_c}\right)^2\right]^{-3\beta+0.5}$$

- Only interested in β which is the slope of the decreasing SB radial profile at large radii



XMM-Newton Subsample

Hydrostatic masses (M)

- The mass inside an X-ray emission radius r, assuming the hydrostatic equilibrium, is:

$$\mathrm{M}(< r) = 3.7\times10^{13} M_{\odot} T(r)\, r \,\frac{3\,\beta\,\gamma\,x^2}{1+x^2}$$

- A polytropic temperature profile: $T(r) \propto n_{gas}^{\gamma-1}$ is assumed with γ = 1.1

X-ray luminosities (L_X)

- L_X is calculated by fitting a source spectral model to the observed X-ray spectrum and obtaining the flux which is then converted to luminosity using the distance (K-correction)

Halo concentrations (c)

- The dark matter halo concentration is a property of the mass profile which measures how mass is concentrated in the inner parts of the group: $c = \frac{r_{vir}}{r_s}$, $M_{vir} \propto \frac{1}{c}$

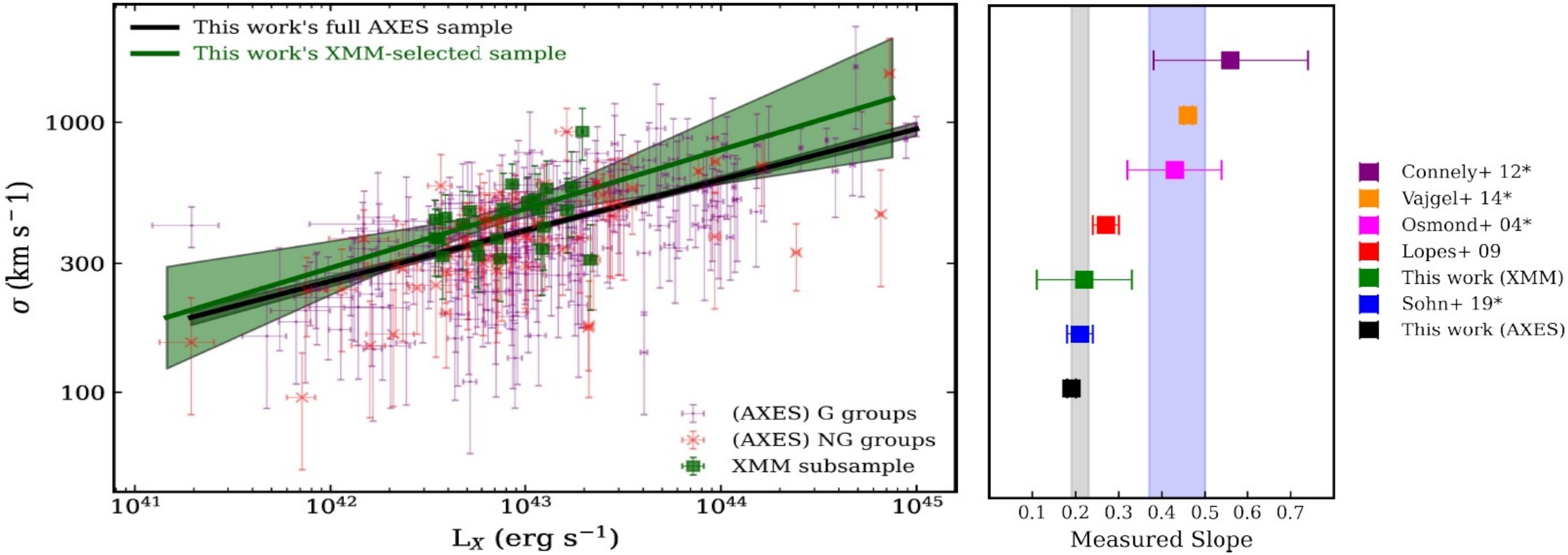
- r_s is the scale radius, or the radius at which the density changes from $\propto r^{-1}$ to $\propto r^{-3}$

- The concentration code is taken from Hu & Krastov (2003) and it uses M, σ_v, Δ, z as inputs

Scaling relations

$\sigma_v - L_X$ relation

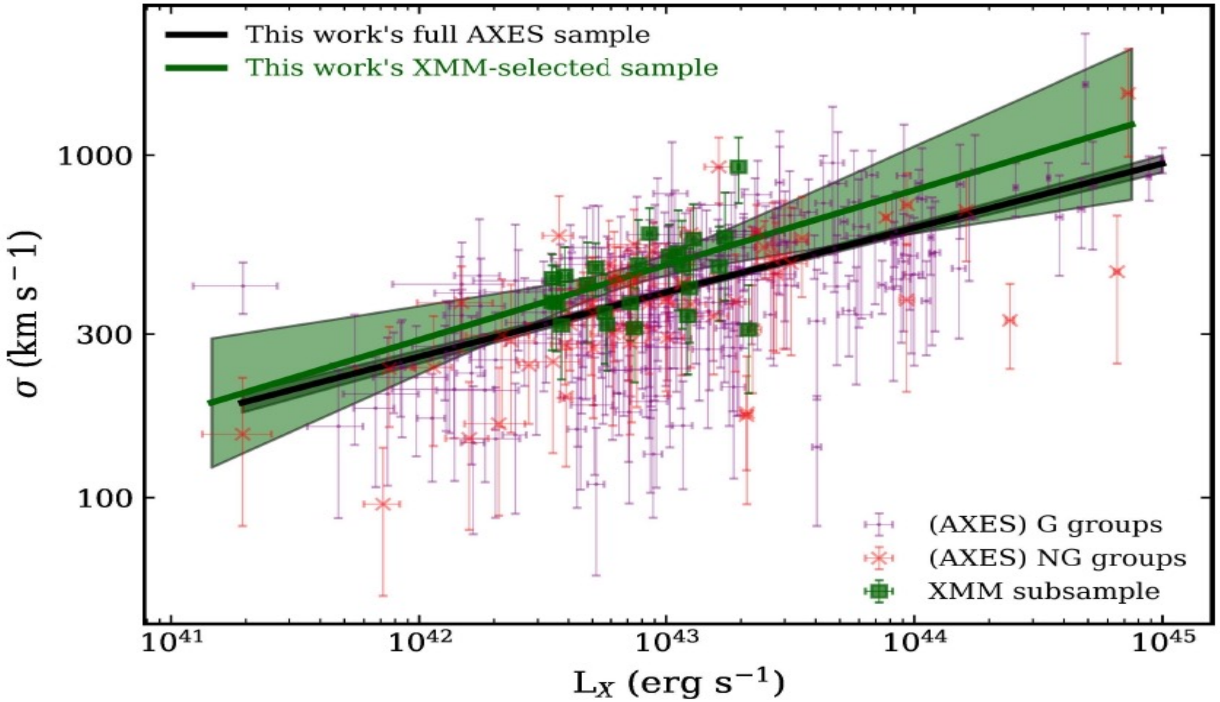
- $\sigma_v \propto (L_X)^{0.22\pm0.11}$ for the XMM subsample and $\sigma_v \propto (L_X)^{0.19\pm0.01}$ for the full AXES-2MRS sample
- Self-similar/theoretical expectation is $\sigma_v \propto (L_X)^{0.25}$ and the calibrated band-limited relation is shown in grey while the bolometric relation in blue

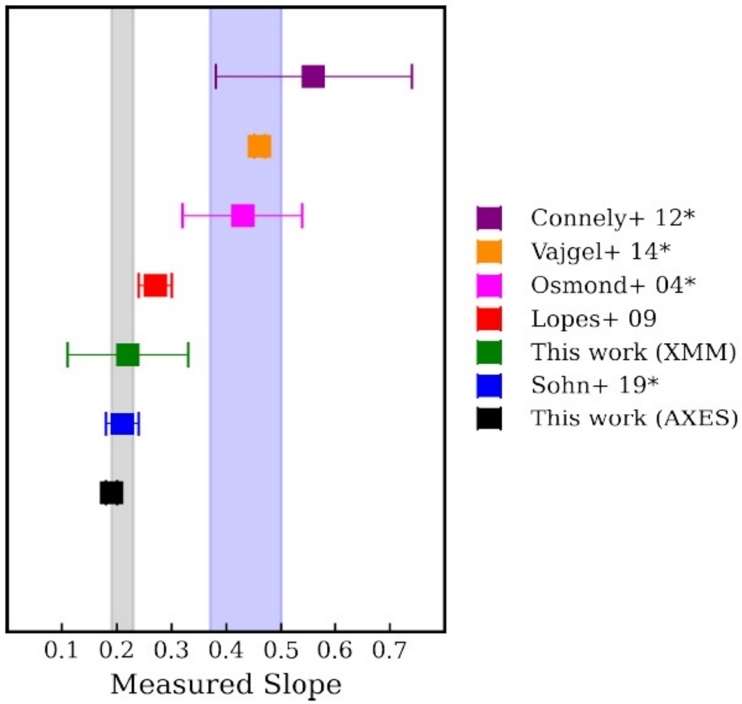


Scaling relations

$\sigma_v - L_X$ relation

- The XMM subsample is comparable to the full AXES-2MRS catalogue (important!)
- Based on this relation, the new low-z AXES-2MRS shows similar characteristics to the distant COSMOS sample (Sohn et al. 2019)

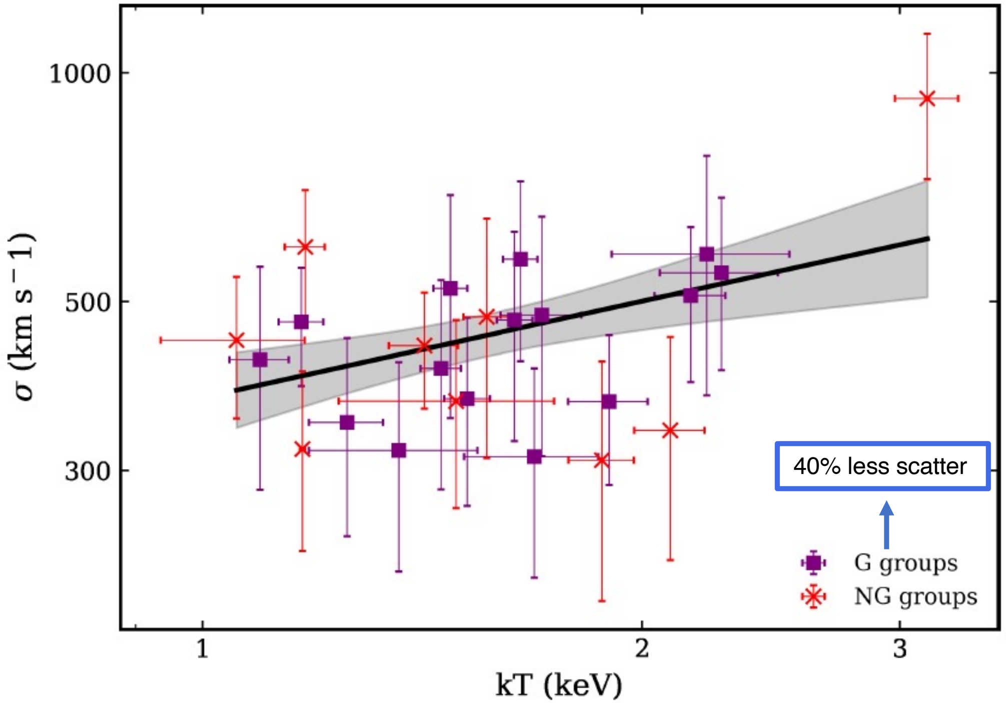


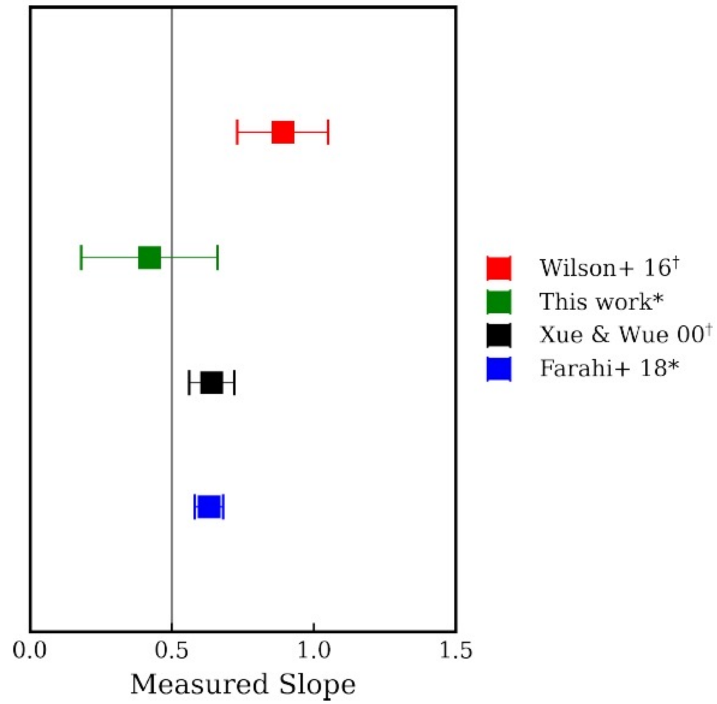


Scaling relations

$\sigma_v - kT$ relation

- $\sigma_v \propto (kT)^{0.42\pm0.24}$ for the XMM subsample. Self-similar expectation is $\sigma_v \propto (kT)^{0.5}$
- Least intrinsic scatter of all studies

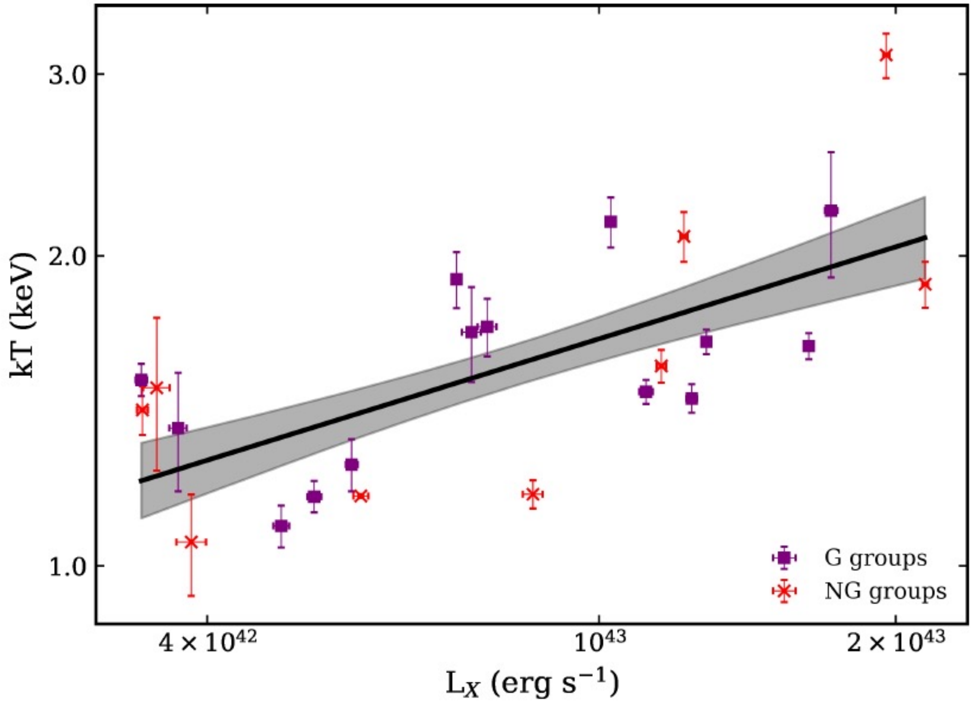


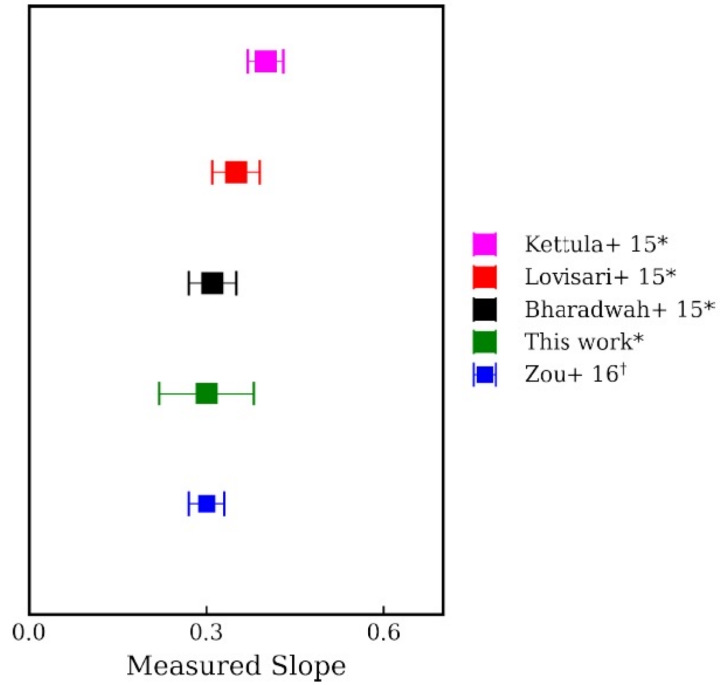


Scaling relations

$kT - L_X$ relation

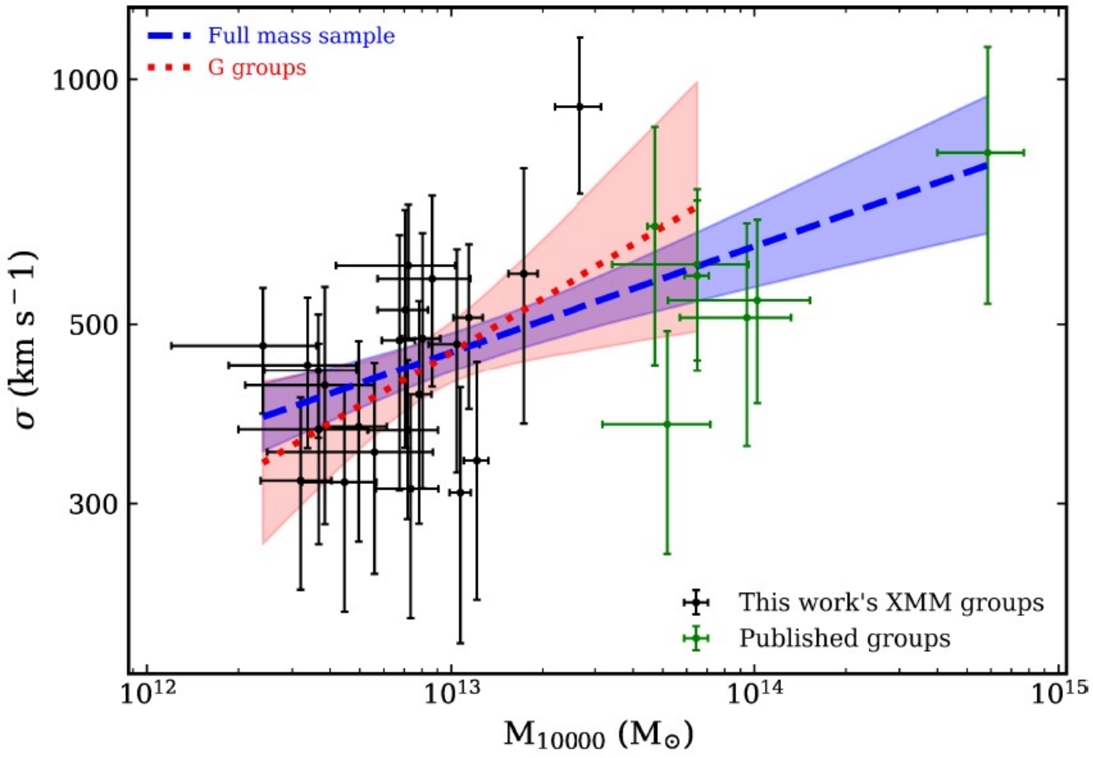
- $kT \propto (L_X)^{0.3\pm0.08}$ for the XMM subsample agreeing with the published works. Purely gravitational expectation is $kT \propto (L_X)^{\sim0.67}$
- The obtained result stands for a notable effect for non-gravitational heating





Scaling relations
$\sigma_v - M$ relation

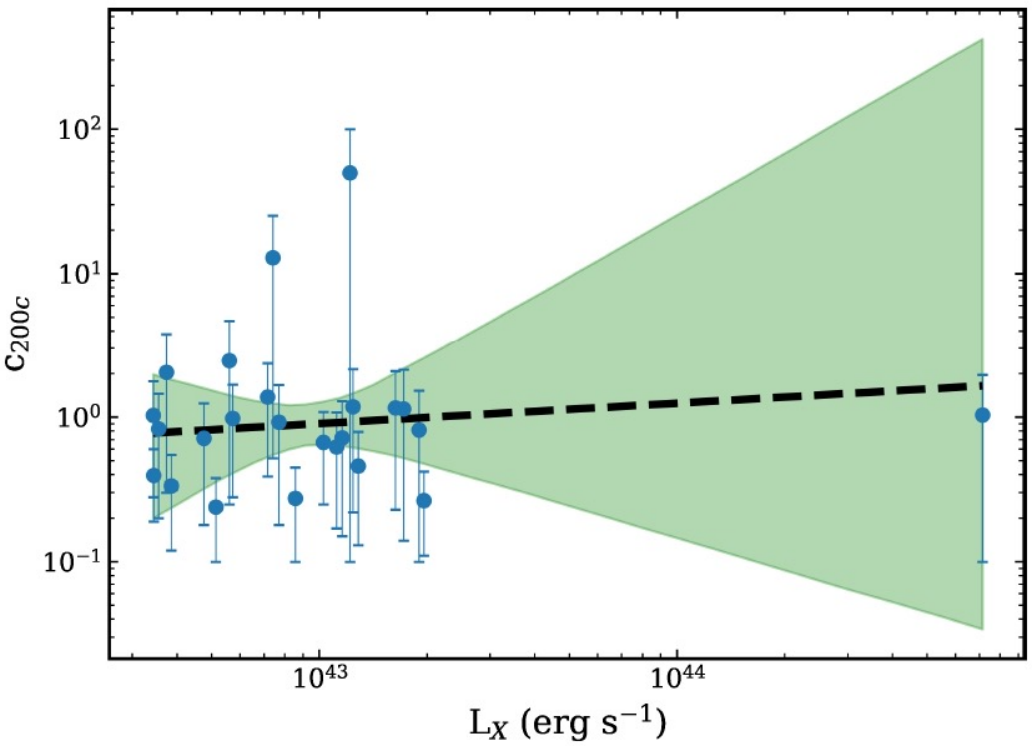
- $\sigma_v \propto (M)^{0.13 \pm 0.05}$ for the XMM subsample. Several high-mass AXES-2MRS groups were added from the literature



Scaling relations

c $- L_X$ relation

- $c \propto (L_X)^{0.14 \pm 11.36}$ for the XMM subsample with a large intrinsic scatter of 0.76. c is hypersensitive to variations in σ_v (which has errors on the order of 20-30%)



Summary & discussion

- Observational astronomy is an extremely data-driven field and with new data comes new catalogue possibilities
- Cataloguing objects is very important as changing the cataloging method will change the results
- An open question: what is the best cataloguing method?
- AXES-2MRS is designed to capture the baryonic content of galaxy groups in the local universe
- AXES-2MRS captures back some of the often-missed faint systems with enhanced representation of the low-z low-luminosity space
- AXES-2MRS allows for quality studies of the local low-z universe (already signs of redshift invariance from the $\sigma_v - L_X$ relation)

Summary & discussion

- You should use AXES-2MRS when doing science with galaxy groups at low redshift

- AXES-2MRS should be compiled with larger catalogues for a more complete literature

Summary & discussion

- You should use AXES-2MRS when doing science with galaxy groups/clusters at low redshift
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Thank you!

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- Based on this relation, the new low-z AXES-2MRS shows similar characteristics to the distant COSMOS sample (Sohn et al. 2019)

- The XMM subsample is comparable to the full AXES-2MRS catalogue (important!)