LoCuSS: A survey of X-ray groups being accreted by massive galaxy clusters

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Cosmic mergers, Birmingham, 21st September 2017

Galaxy clusters are expected to form and grow hierarchically, primarily through the merger of lower mass clusters and the accretion of group-mass halos

Clusters assemble late, doubling their masses since $z \sim 0.5$

There should thus be numerous group-mass halos in the outer regions of clusters, that are about to be accreted

Motivates a survey of X-ray groups in the vicinity of a statistical sample of massive clusters.

What is the mass function of infalling groups? Is it biased with respect to that seen in wide-field surveys?

How much mass is being accreted onto clusters in the form of groups? Is it enough to explain the mass growth of the clusters themselves?

Create sample for studying effect of pre-processing on the galaxies within these infalling groups (Matteo Bianconi's talk)

LoCuSS: The Local Cluster Substructure Survey

- Survey of 30 X-ray luminous clusters at $0.15<z<0.30$ from ROSAT All Sky Survey cluster catalogues ($M_{200} > 3\times10^{14}\,M_\odot$; Okabe *et al.* 2010)

- All 30 clusters have Subaru-based weak lensing masses (Okabe+2010,2016), plus XMM/Chandra imaging, from which mass profiles have been derived out to r_{200} (Martino+2014)

- Wide field *J,K* and optical imaging to $3r_{200}$, Spitzer and Herschel data.

- Arizona Cluster Redshift Survey:

Massive spectroscopic follow-up of K-band (stellar mass) selected galaxy sample for all 30 clusters, resulting in 10,000 cluster members, 80% complete to K*+1.5 ($M^*\sim2\times10^{10}M_\odot$), and extending out to $\sim3r_{200}$.

Cluster name	Redshift	N_z (literature)		Cluster name	Redshift	N_z (literature)	
Abell 68	0.2510	194	(0)	Abell 1835	0.2520	1083	(608)
Abell 115	0.1919	213	(36)	Abell 1914	0.1671	454	(65)
Abell 209	0.2092	393	(49)	Abell 2218	0.1733	342	(49)
Abell 267	0.2275	230	(139)	Abell 2219	0.2257	628	(297)
Abell 291	0.1955	126	(0)	Abell 2345	0.1781	405	(39)
Abell 383	0.1887	266	(92)	Abell 2390	0.2291	517	(140)
Abell 586	0.1707	247	(21)	Abell 2485	0.2476	196	(0)
Abell 611	0.2864	297	(7)	RXJ0142.0+2131	0.2771	204	(15)
Abell 665	0.1827	359	(31)	RXJ1720.1+2638	0.1599	473	(114)
Abell 689	0.2786	287	(102)	RXJ2129.6+0005	0.2337	334	(78)
Abell 697	0.2818	486	(141)	ZwCl0104.4+0048	0.2526	185	(1)
Abell 963	0.2043	466	(50)	ZwCl0823.2+0425	0.2261	337	(4)
Abell 1689	0.1851	857	(416)	ZwCl0839.9+2937	0.1931	173	(3)
Abell 1758	0.2775	471	(50)	ZwCl0857.9+2107	0.2344	147	(0)
Abell 1763	0.2323	423	(126)	ZwCl1454.8+2233	0.2565	157	(1)

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Detection and identification of infalling X-ray groups

- Existing XMM data for 23/30 clusters that had been obtained in order to derive masses, mass profiles, and study the ICM (Martino et al. 2014)

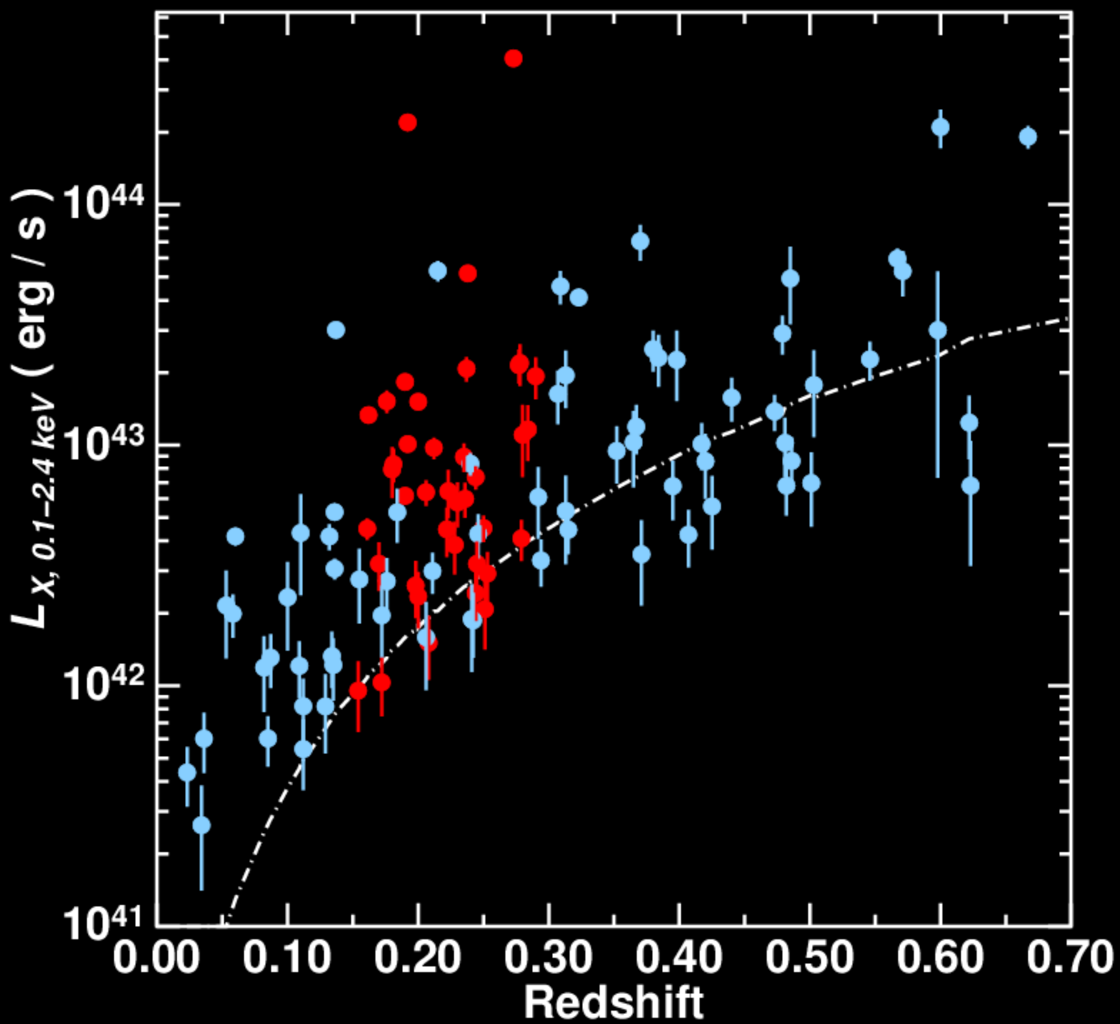
- Search for other extended X-ray sources in the XMM images.

- The 0.5-2keV band image is decomposed into unresolved and extended sources, using wavelet scale-wise decomposition and reconstruction technique (Vikhlinin+1998) on scales 8-64” (e.g. Finoguenov+2009). Point sources are modelled using XMM PSF model and removed.

- Optical counterparts of extended X-ray sources identified using deep Subaru imaging and available redshift data.

- Most groups have obvious BCG with known redshift and/or many spectroscopic members within ±500 km/s

The detected X-ray groups



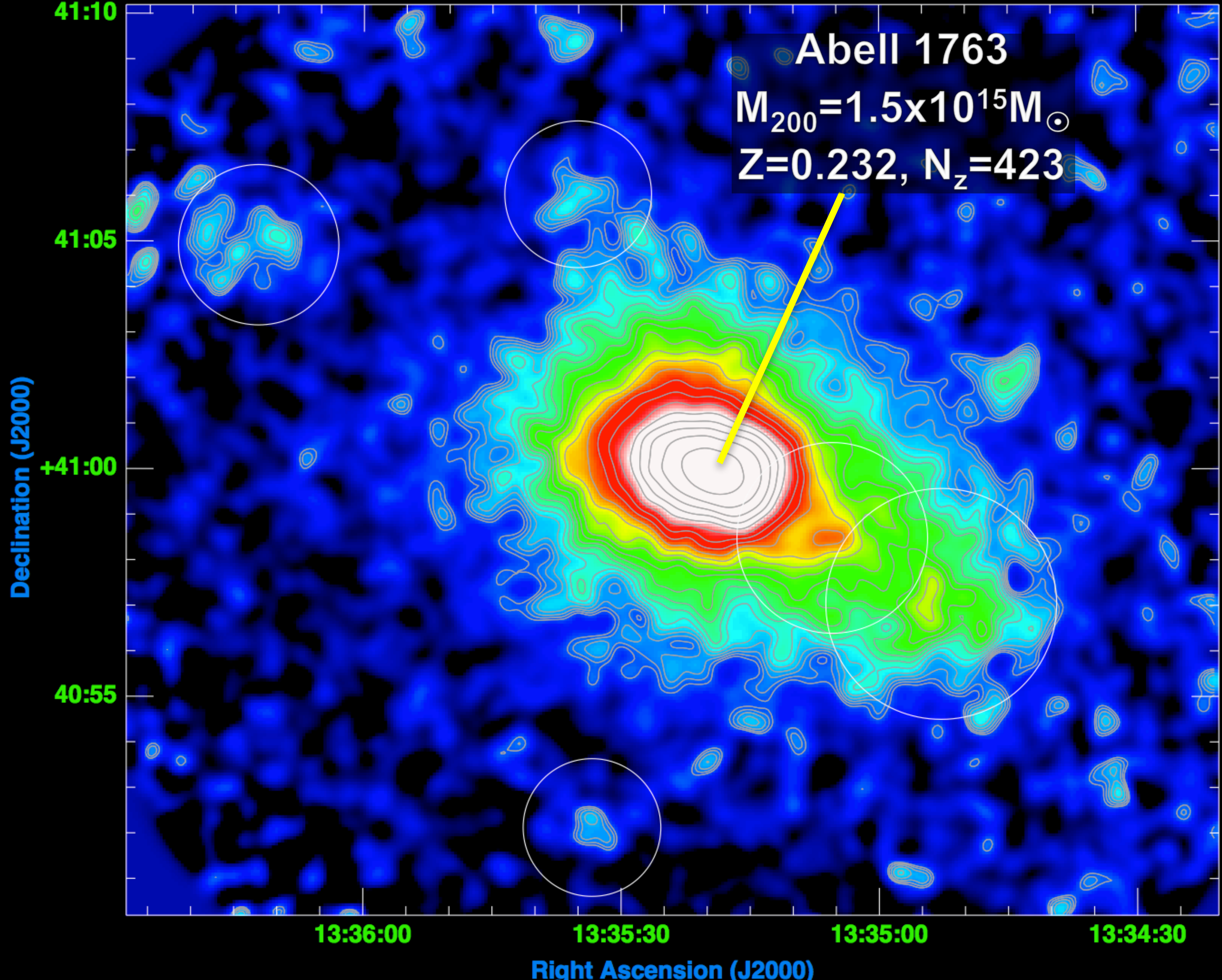
91 X-ray groups identified over the 23 XMM fields with SNR>3.0 and optical counterpart (galaxies)

90 have confirmed redshift in range 0.023-0.7, other group is at z>0.5

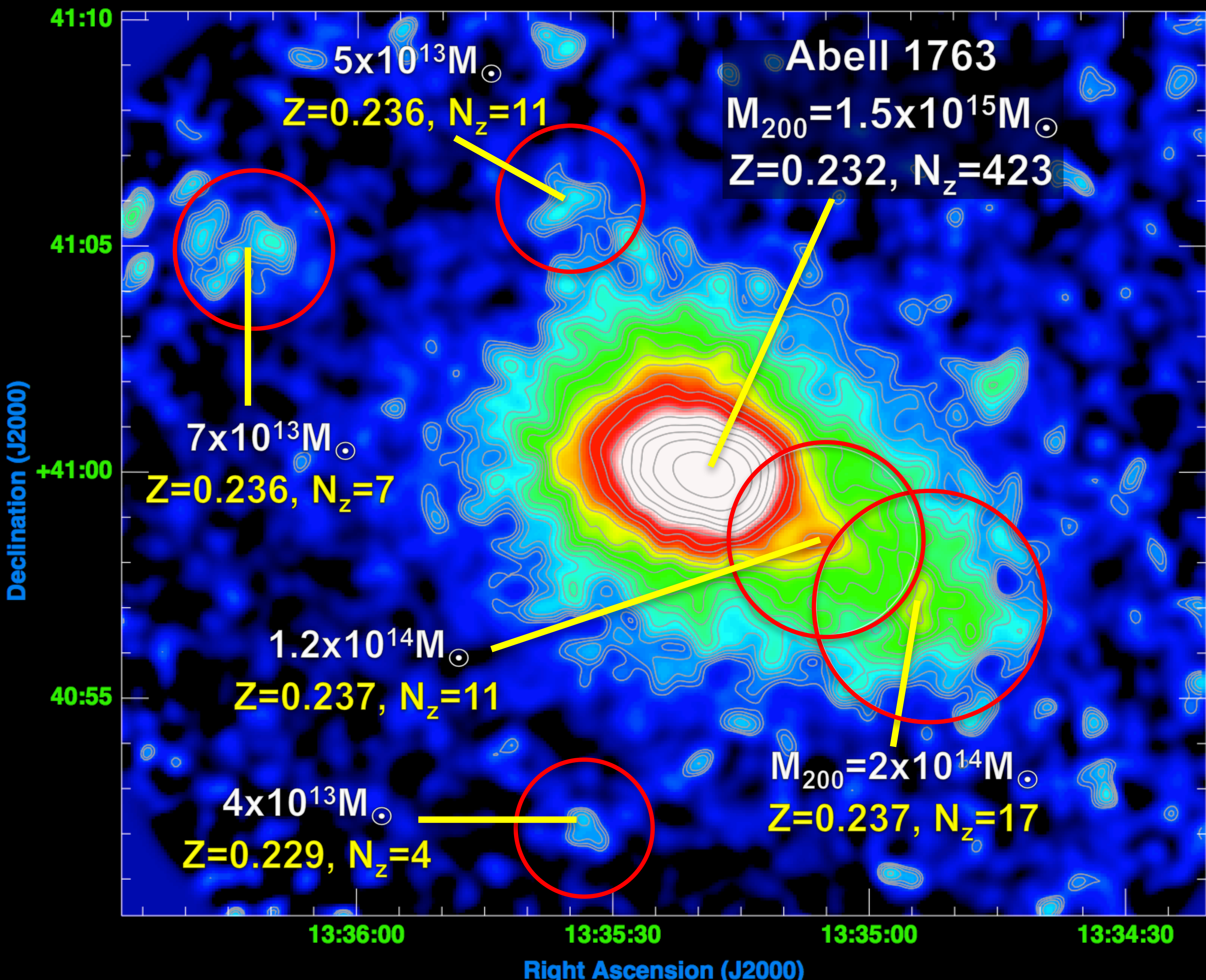
39 X-ray groups found at redshift of primary cluster (30/39 have ≥7 members)

L_X => M_{200} using WL scaling relation of Leauthaud+2010

X-ray groups around Abell 1763



X-ray groups around Abell 1763



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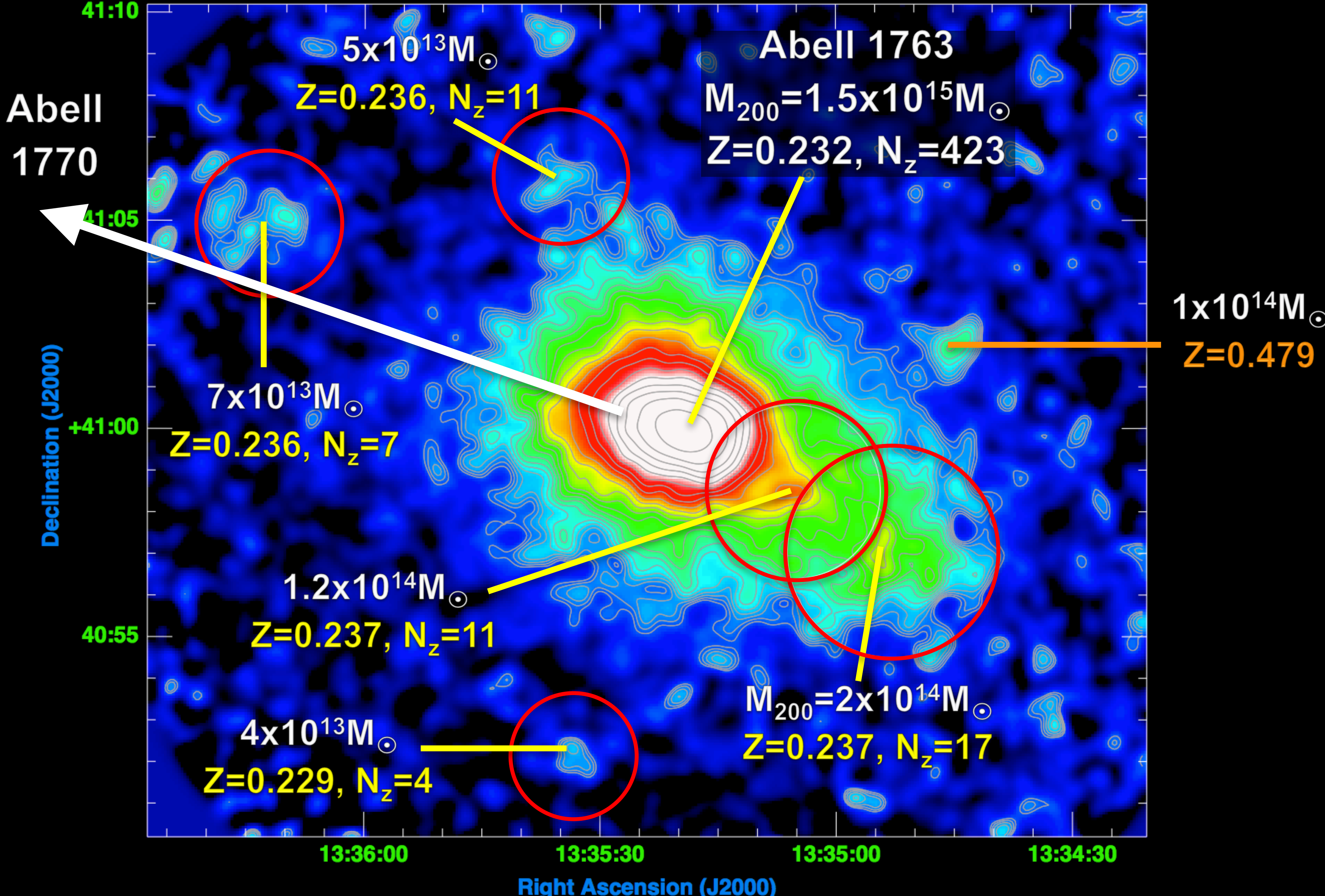
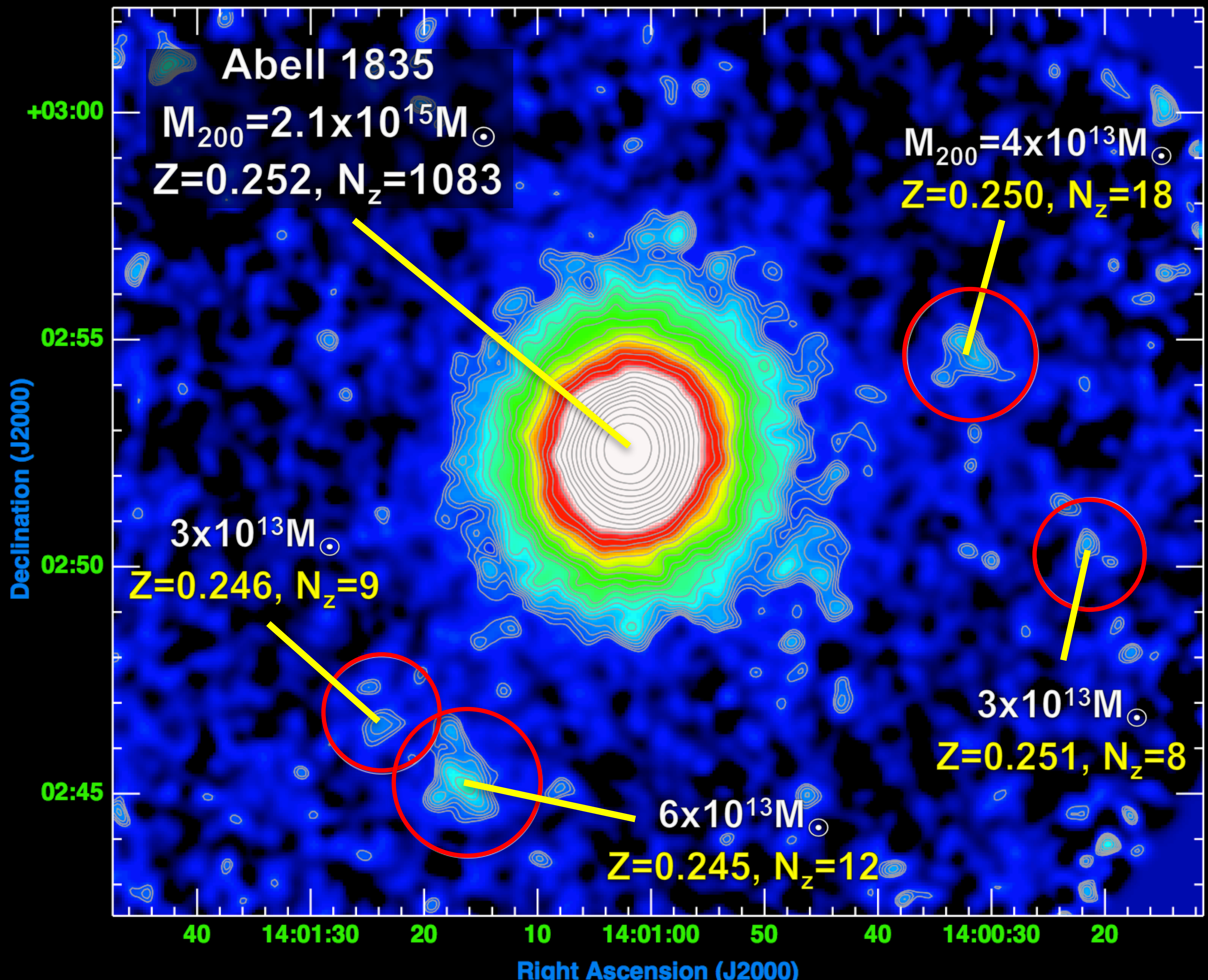
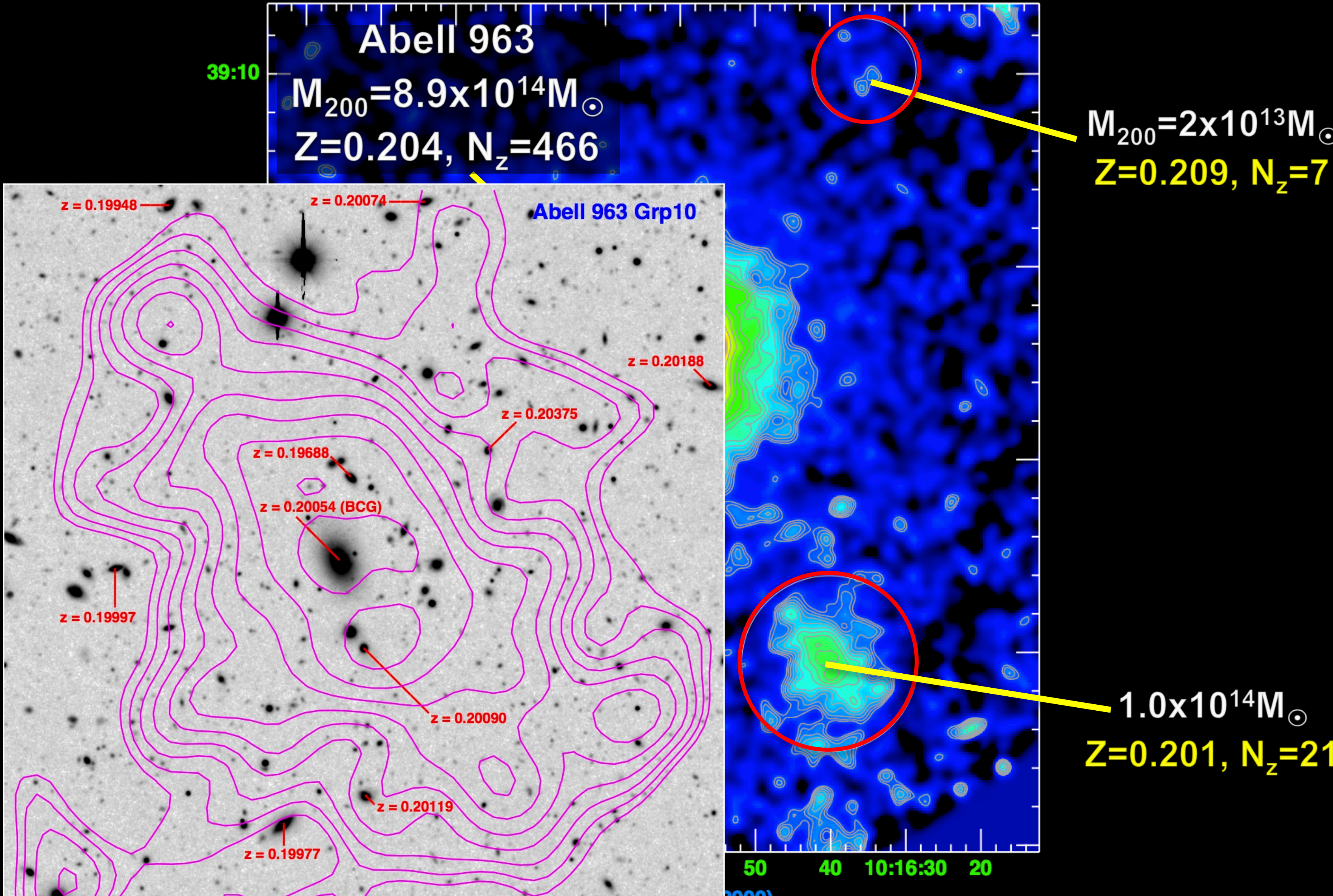


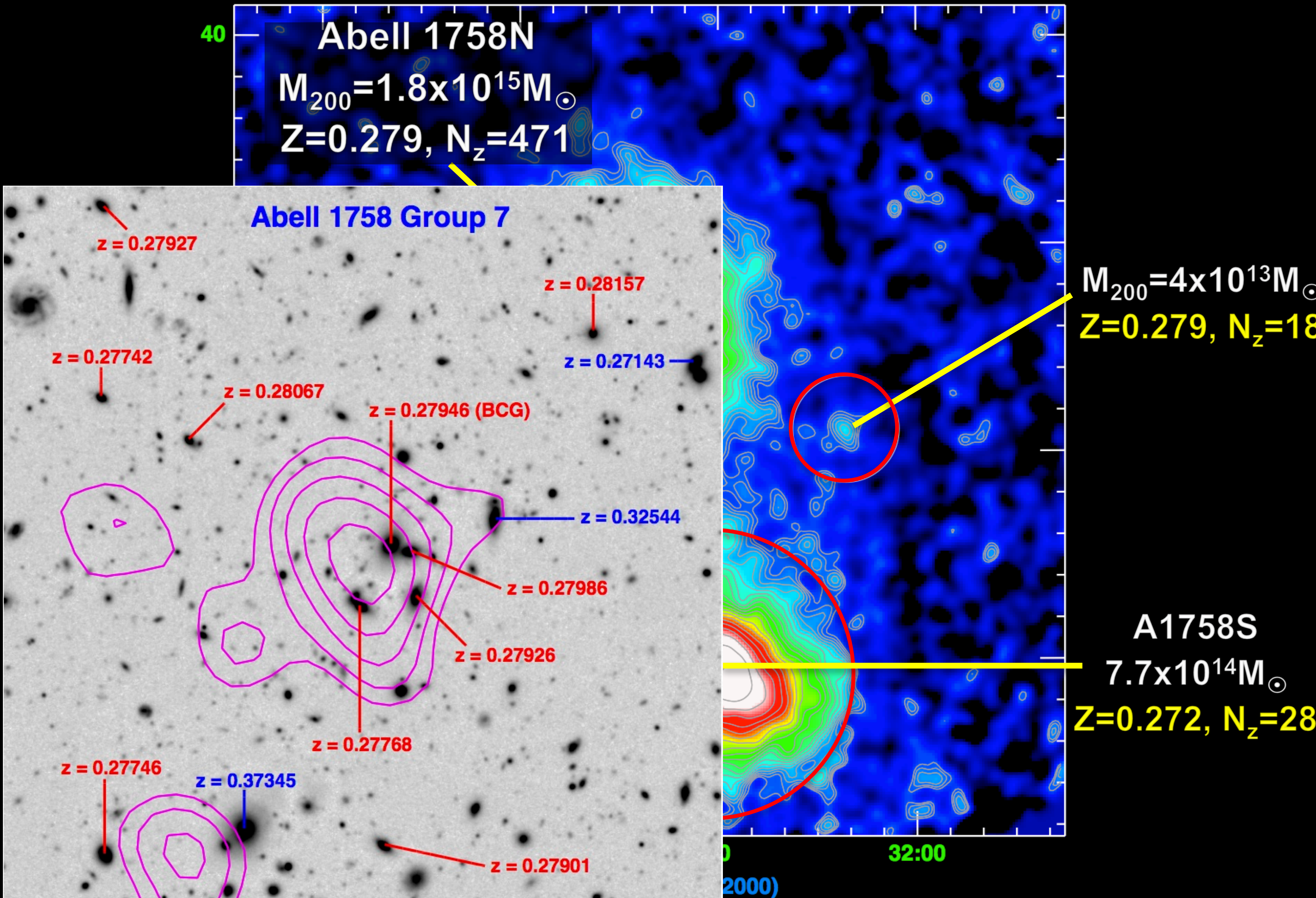
X-ray groups around Abell 1835



X-ray groups around Abell 963



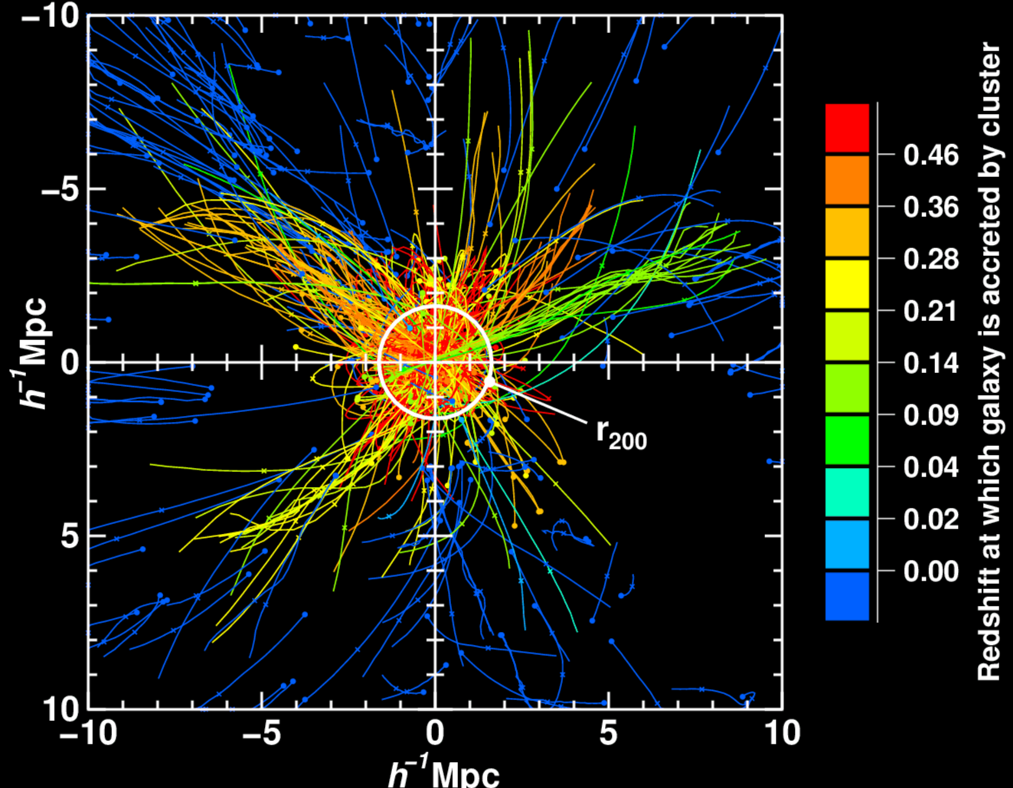
X-ray groups around Abell 1758N



Predictions from cosmological simulations

Extract volumes around the 75 most massive clusters (>5x$10^{14}M_\odot$) in the Millennium simulation. Select DM halos >$10^{13}M_\odot$ within 25Mpc at z=0.21

Create artificial observations. Project along line-of-sight, convert M_{200} to X-ray luminosity, and add each group to the XMM images one at a time.

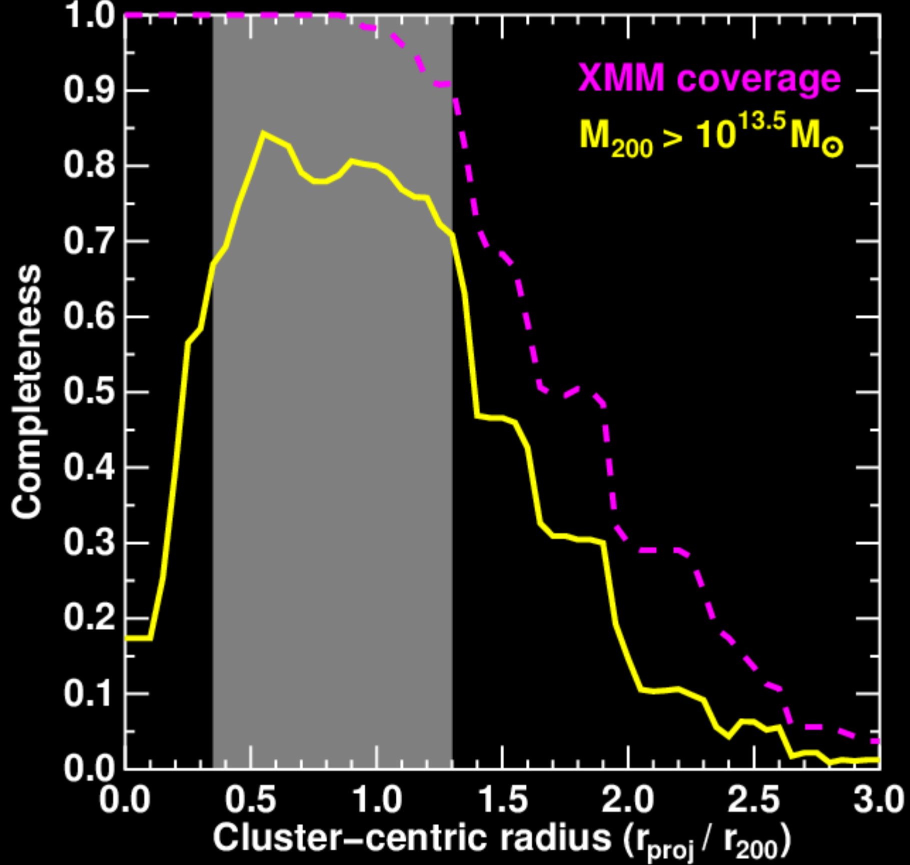


Measure completeness of XMM images as a function of M_{200} and distance from cluster centre

Follow orbits of DM halos in the Millennium simulation to find epoch at which they are accreted

Follow the mass growth rate of the primary clusters

The completeness of the X-ray survey

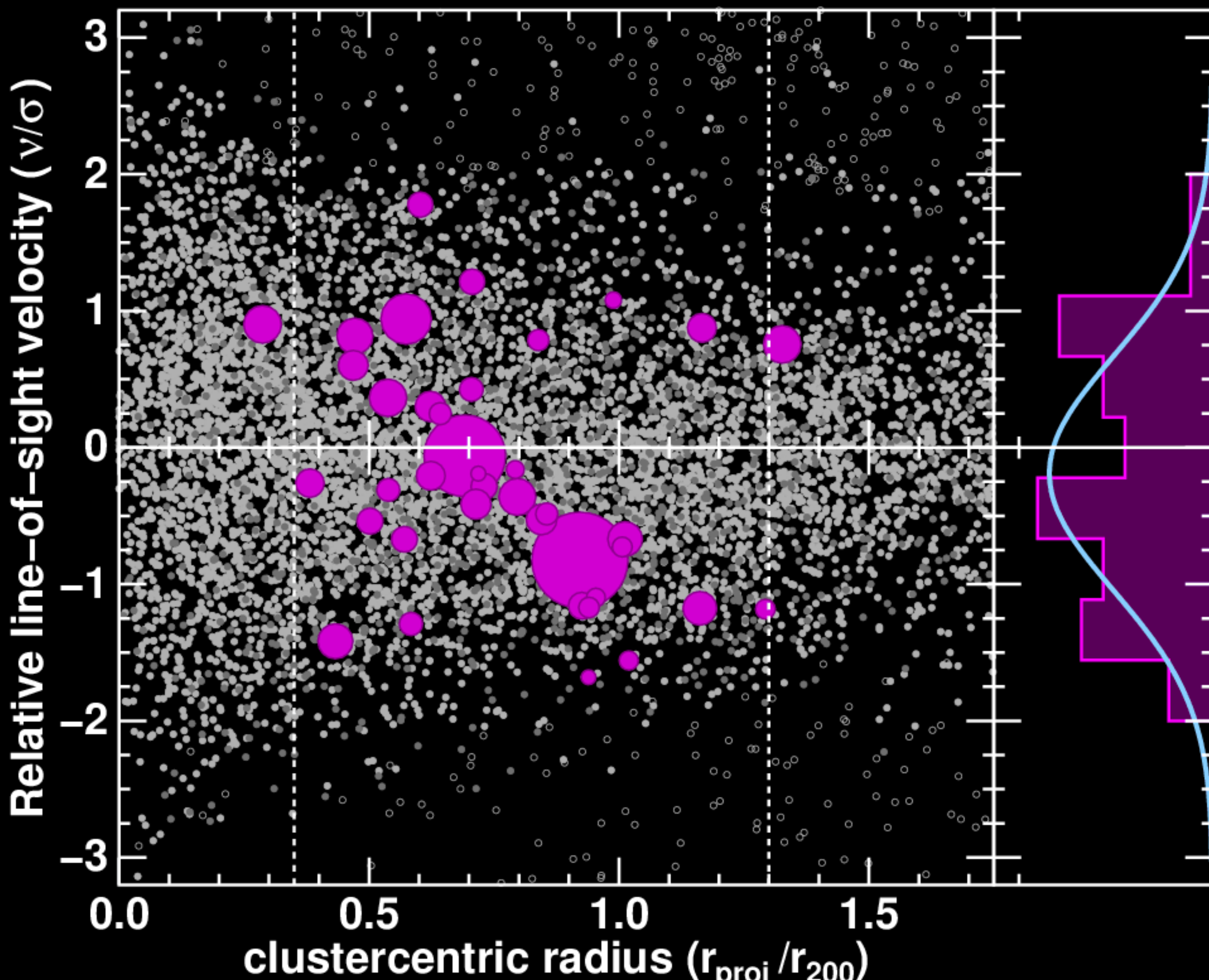


Cannot detect groups in the very cores of the clusters due to the much brighter cluster ICM.

Limited at large cluster-centric radii by the size of the XMM fields.

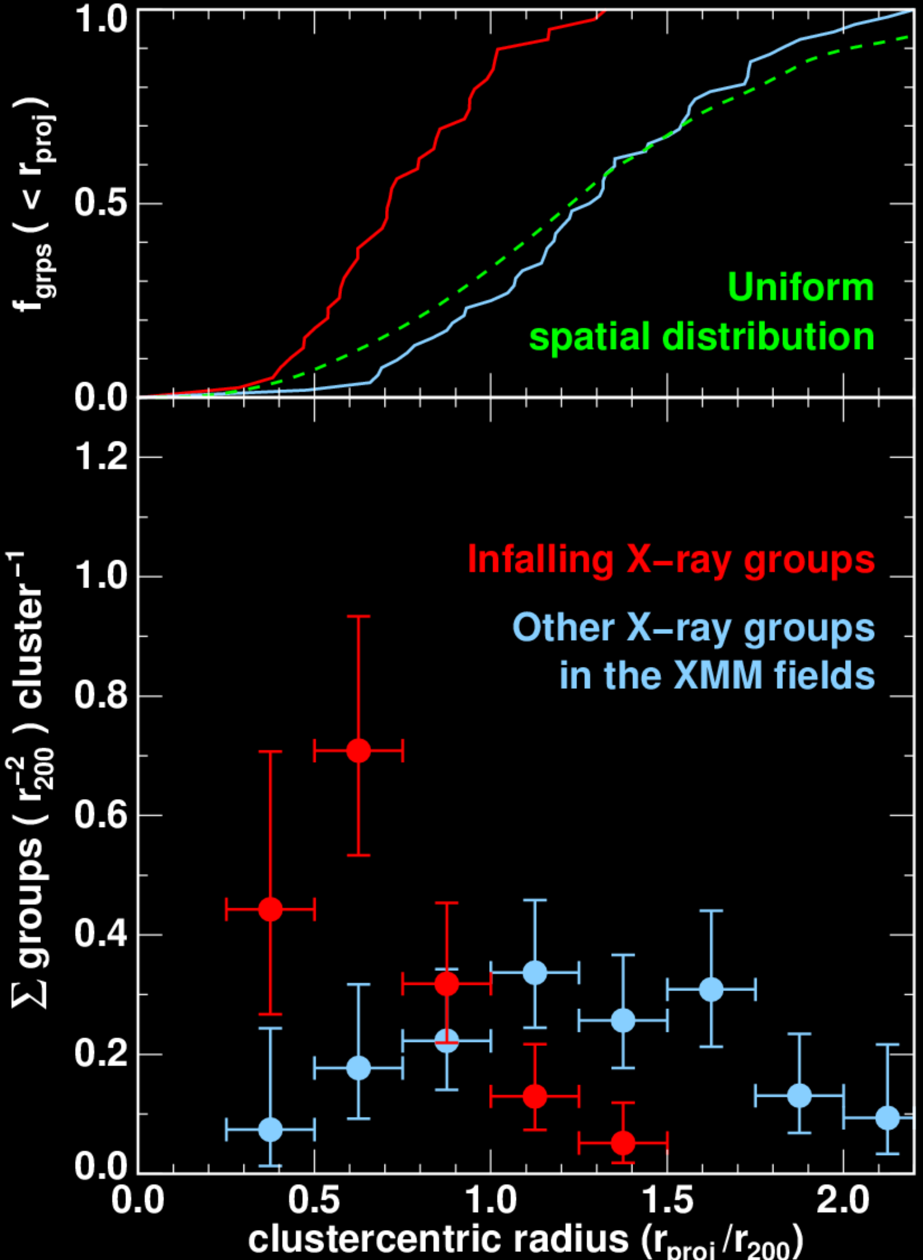
Highest completeness for detecting groups at $0.35\text{-}1.3r_{200}$

Location of the X-ray groups in the caustic diagram



The velocity distribution of the X-ray groups is non-Gaussian, indicative of being an infalling population

Radial distribution of the infalling X-ray groups



The 39 infalling X-ray groups are found much closer to the primary cluster on average than the other 52 back/foreground groups also detected in the same XMM images (6.0σ result), showing a sharp peak at 0.5-0.75 r_{200}.

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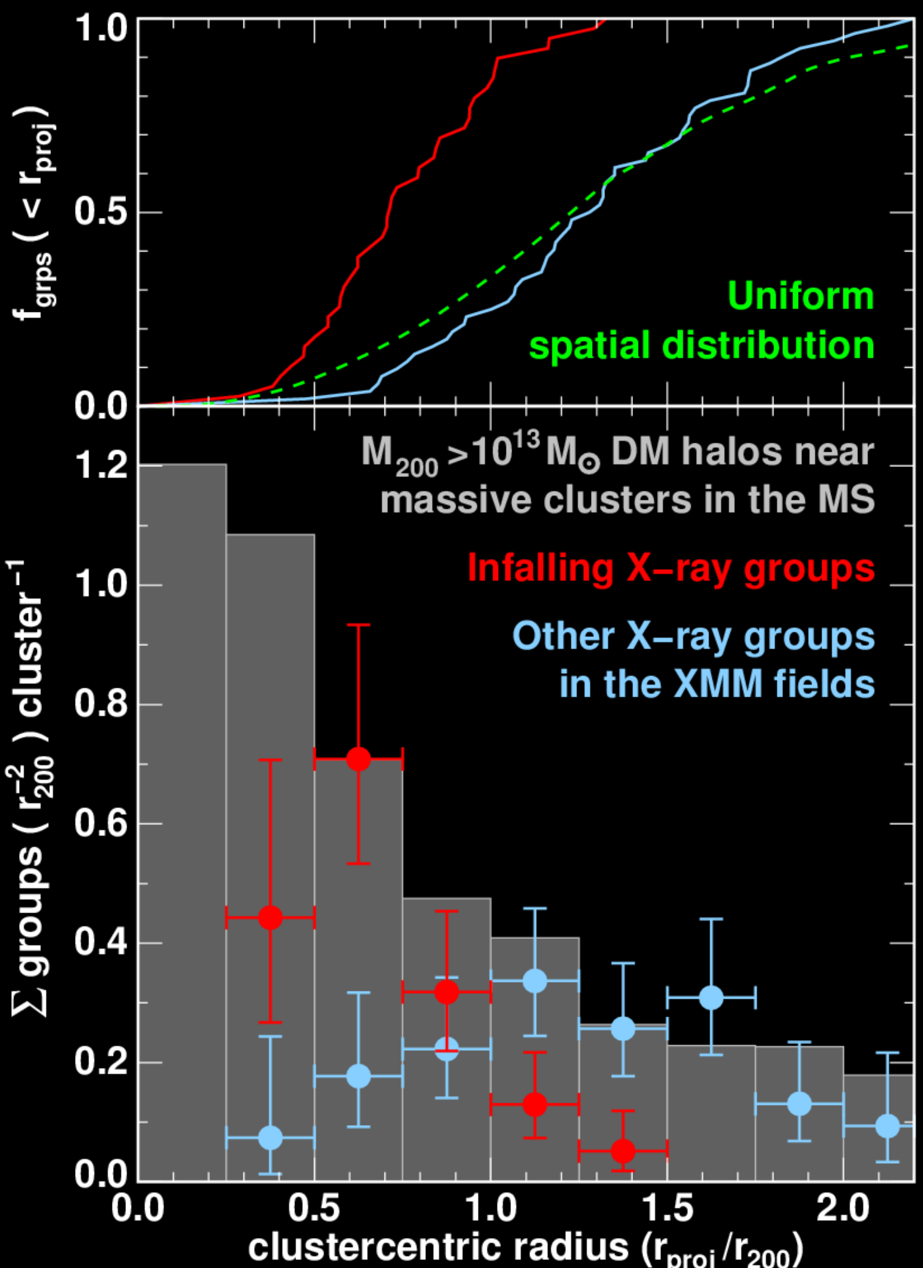

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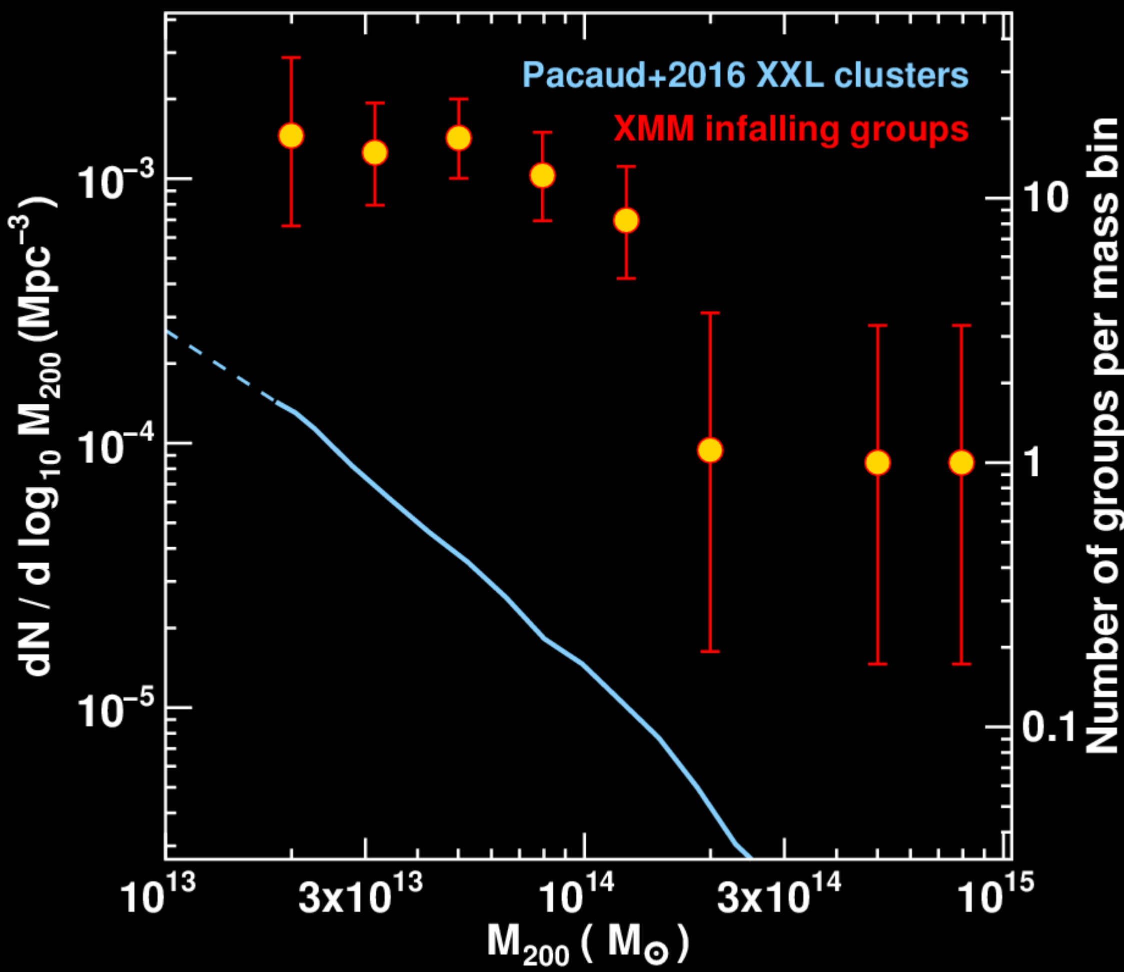
Group-mass DM halos (>$10^{13}M_\odot$) predicted to show sharp increase in number density towards cluster core, just as galaxies do.

The mass function of infalling X-ray groups



Mass function of the infalling XMM groups appears relatively flat for $M_{200}<10^{14}M_\odot$, giving an excess of $\sim10^{14}M_\odot$ systems

Comoving number density of X-ray groups in the vicinity of massive clusters is much higher than that derived from the X-ray LF of groups/clusters in the XXL survey (Pacaud+2016)

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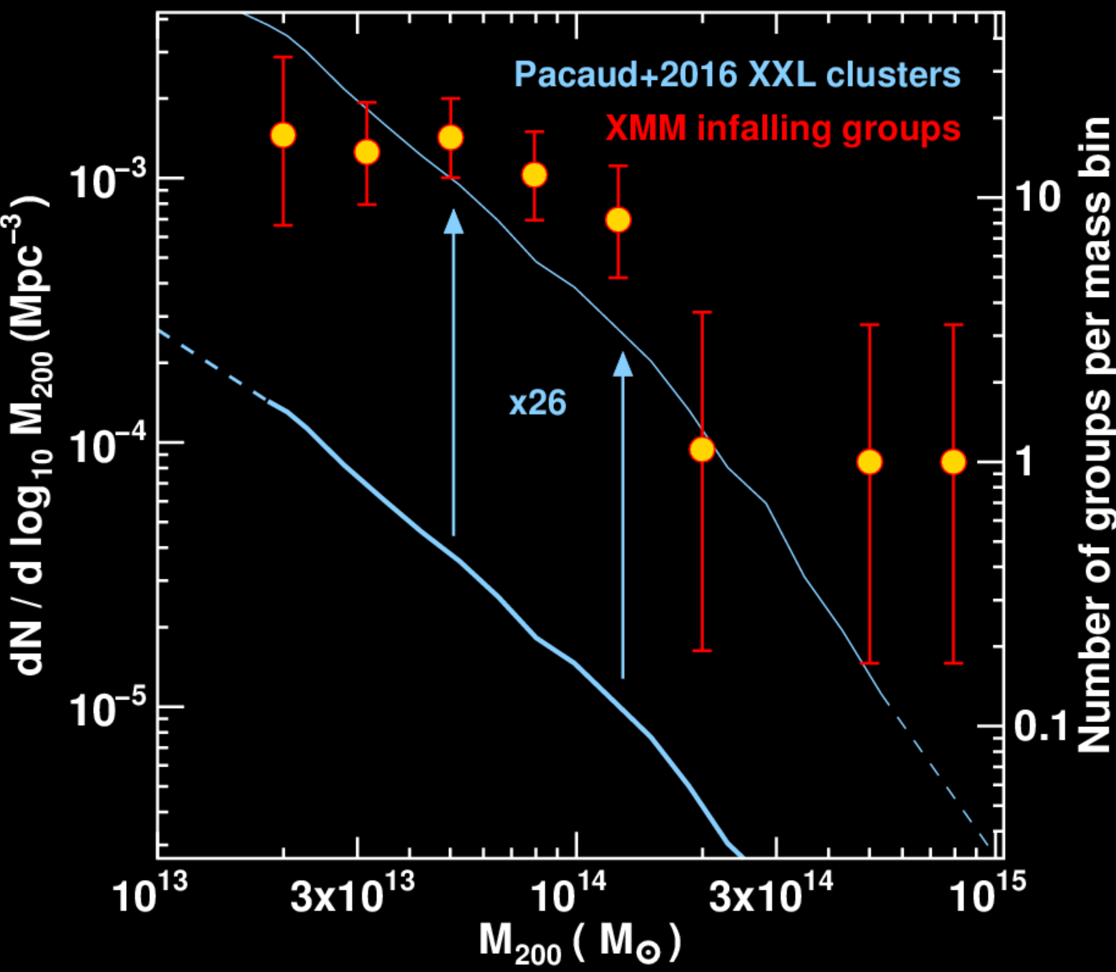

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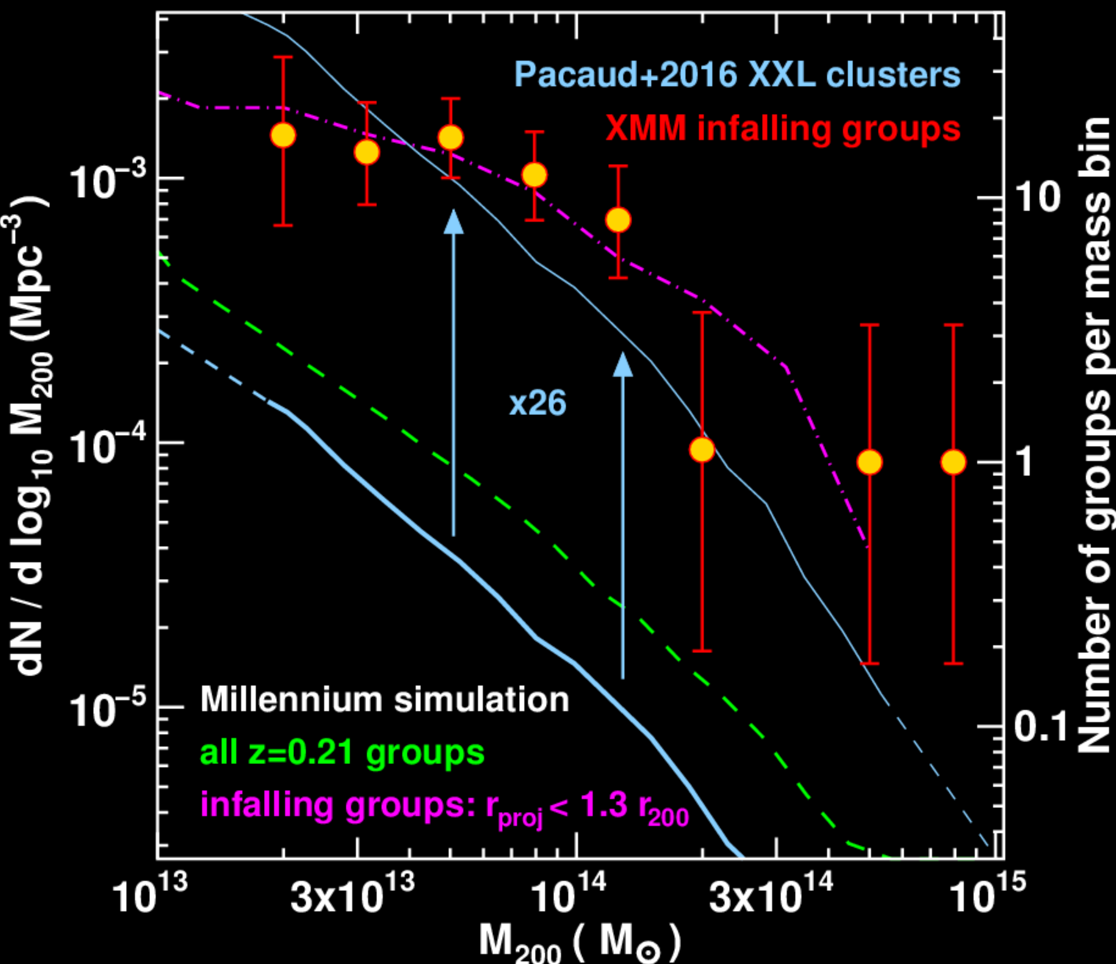

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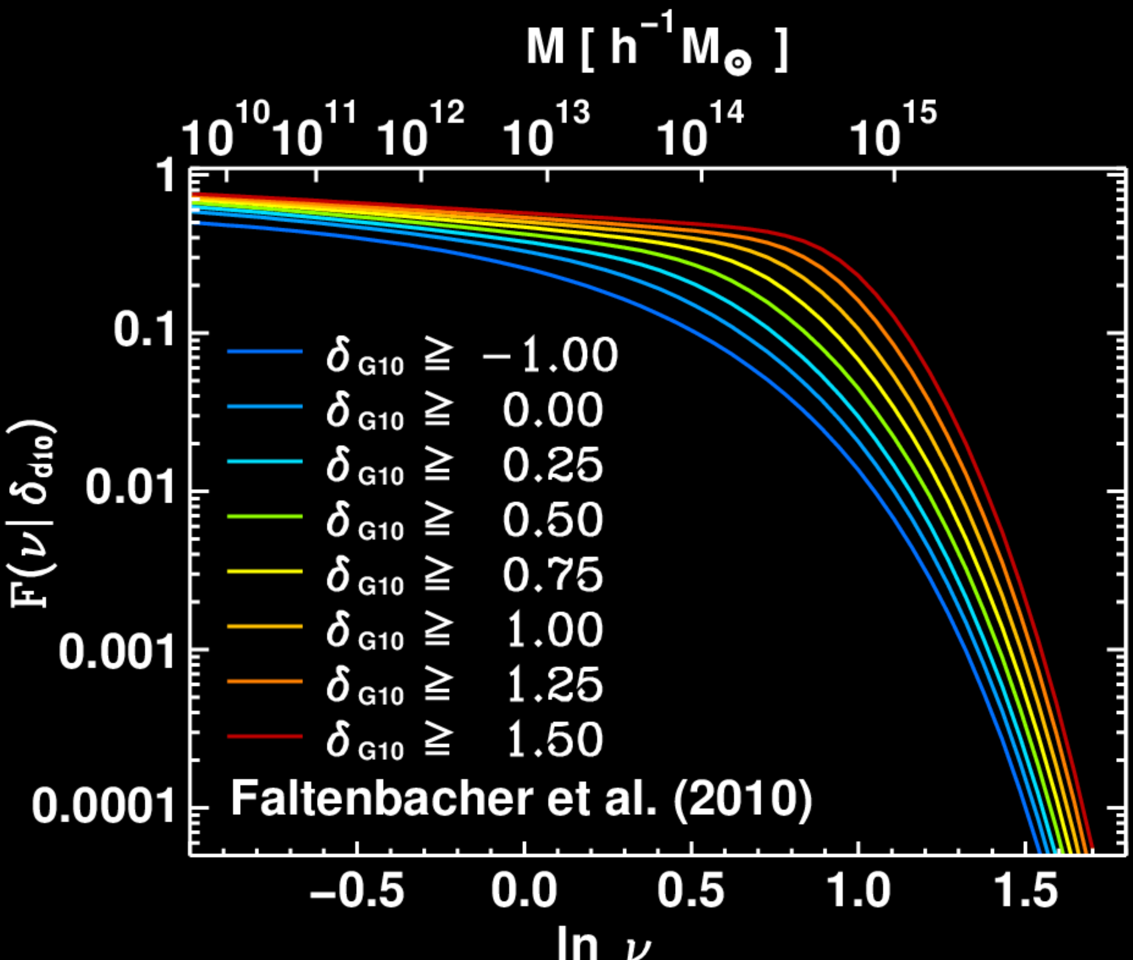
Large overdensity of DM halos in the vicinity of massive clusters, plus turn over in the mass function, rather than simple power-law, reproduces that seen in the Millennium simulation.

Dependence of the halo mass function on density

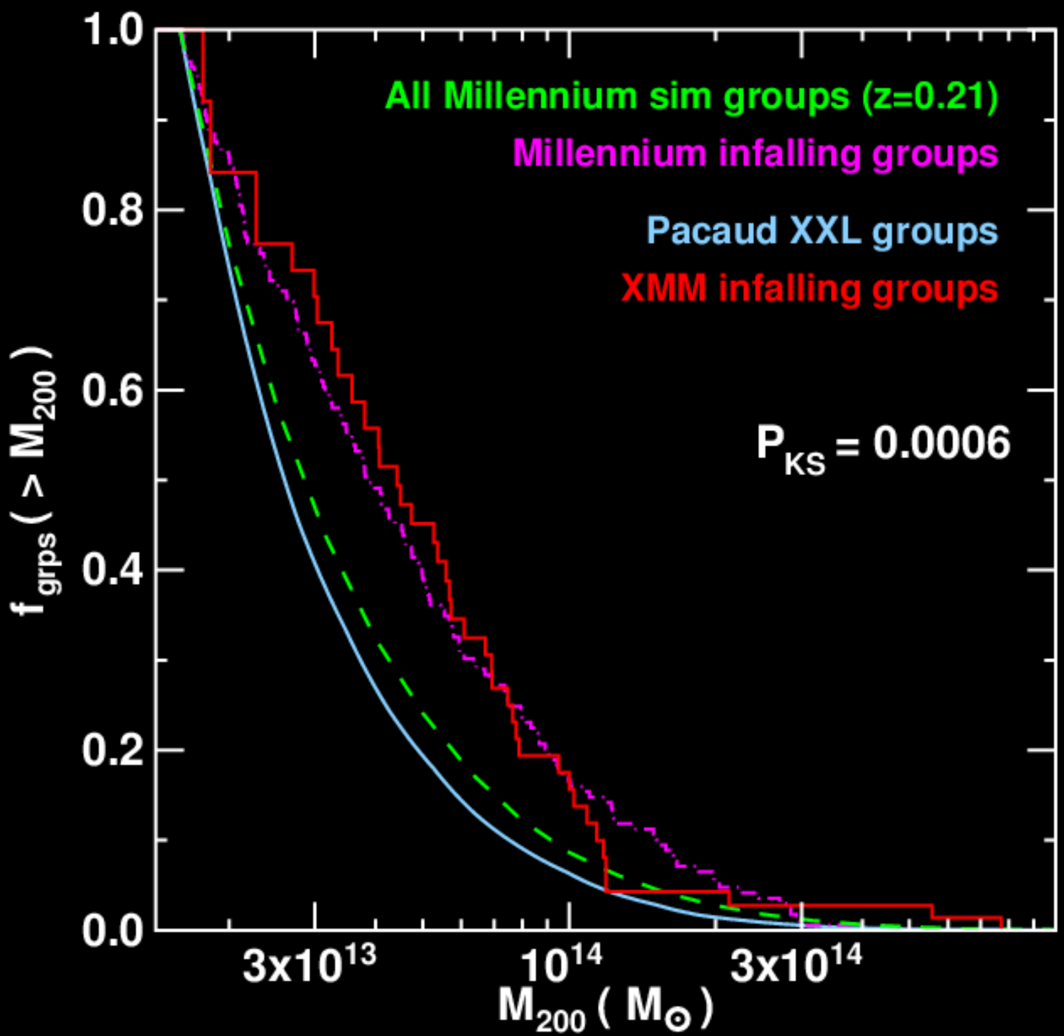


Groups are biased tracers of the large-scale matter distribution, thus are over-represented near clusters relative to lower mass DM halos.

$n(M|\delta) \sim [\ 1+b(M,z)\ \delta\ ]\ n(M)$
(Mo & White 1996)

$\delta_{G10} = (\ \rho[10\mathrm{Mpc}] - \langle\rho\rangle)/\langle\rho\rangle$

The mass function of infalling X-ray groups



The mass function of infalling XMM groups appears “top heavy” relative to that seen in the XXL survey.

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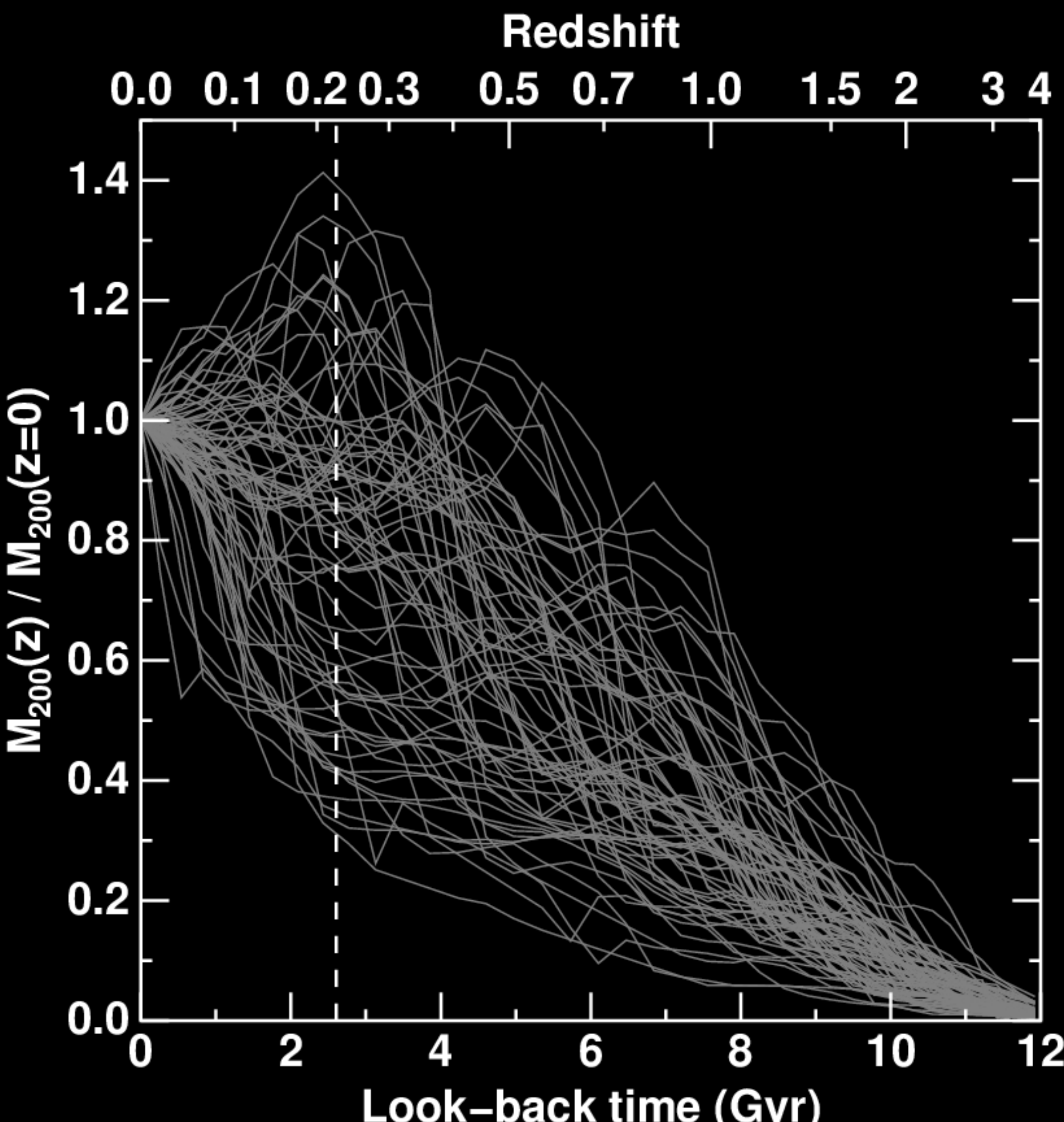
How much mass do these groups contribute?

- The total mass of the 39 groups is $5 \times 10^{15} M_{\odot}$
- …or $2.2 \times 10^{14} M_{\odot}$ per cluster or 19±5% of the cluster's mass
- We assume that all X-ray groups are on their first infall. Ram-pressure stripping should rapidly remove all the X-ray emitting gas as they approach pericenter, leaving trails of gas
- Estimate that 2/3 of the XMM groups will be accreted by the primary cluster by the present day, while 24% of groups accreted by z=0 should be beyond the XMM fields of view at z=0.22.
- Massive clusters should grow by 16±4% from z=0.22 to z=0, due to the accretion of $M_{200} > 10^{13.2} M$ groups.

The mass growth histories of massive clusters



Huge scatter in the mass growth rates of individual clusters => need large samples

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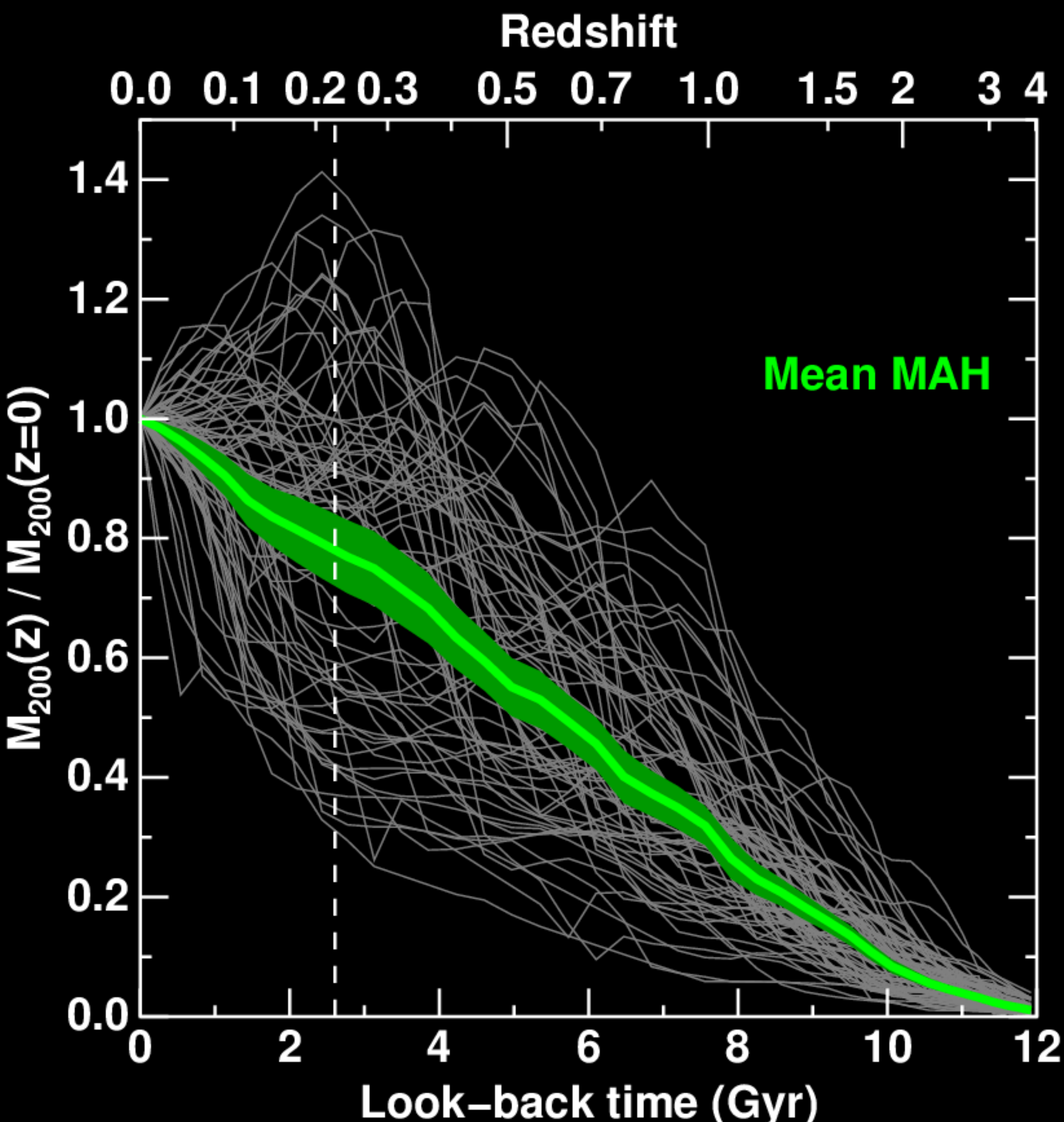

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Clusters expected to increase mass by 25-35% between z=0.22 and present day

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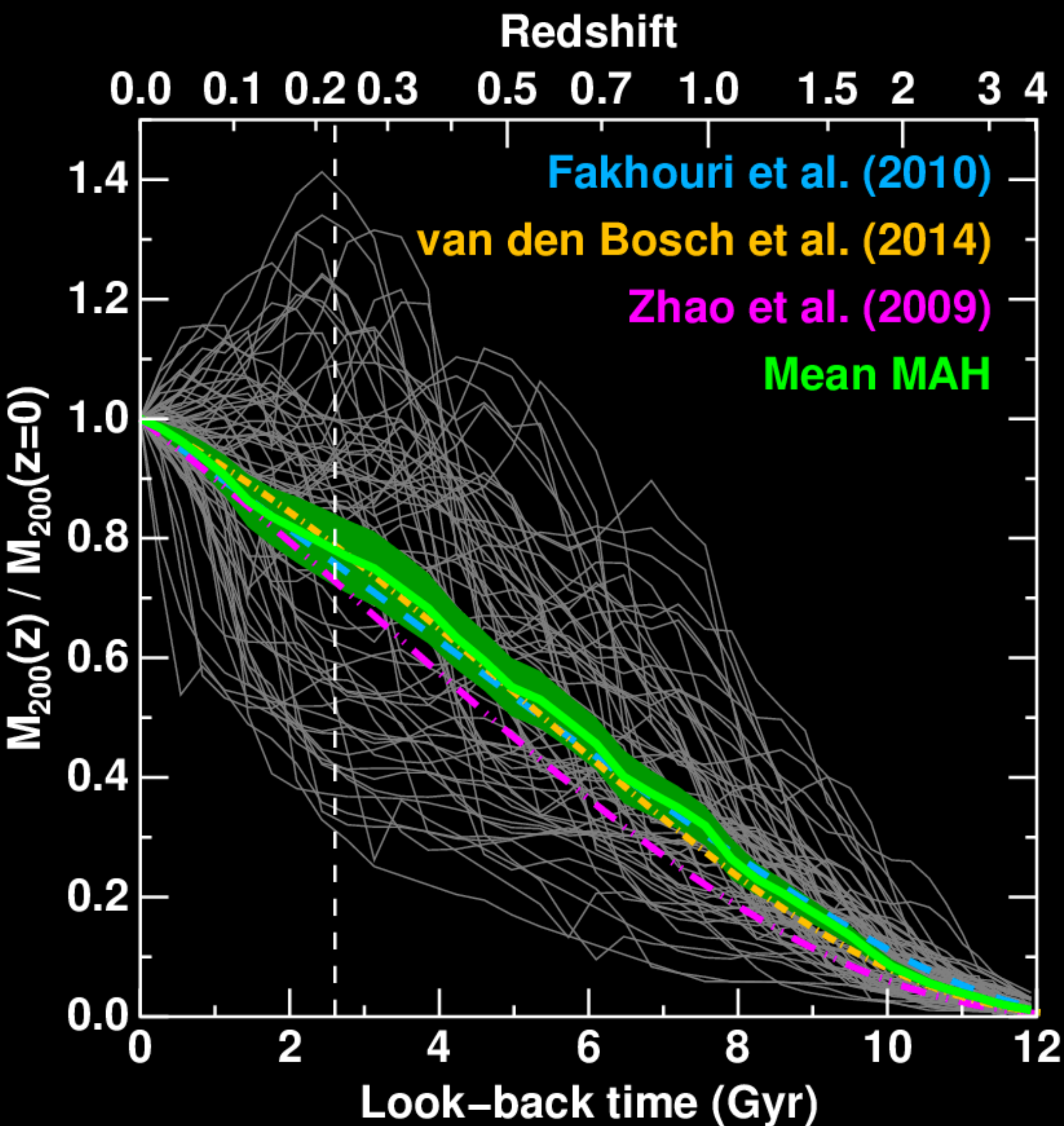

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Half of growth expected to be due to accretion of groups and lower mass clusters. Other half as diffuse accretion of dark matter (Genel+2010)

Summary Haines+2017, arXiv:1709.04945

- Search of the XMM images centred on 23 massive clusters at z~0.2 finds 39 X-ray groups with $M_{200}>10^{13.2}M_{\odot}$ and spectroscopically confirmed to lie within cluster caustics => falling into host cluster.

- Mass function of infalling groups appears biased to high masses

- Estimate that clusters will increase mass by 16% from z=0.22 to present day by accreting these XMM groups

- Groups likely to contribute ~1/2 of mass to cluster growth at late epochs. Rest through smooth accretion of DM (Genel+2010)

- eROSITA will detect such group-mass systems around all massive clusters to z~0.2