XCS: present status and latest results

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on behalf of the XCS collaboration

Galaxy Clusters as Giant Cosmic Laboratories
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XCS
XMM Cluster Survey

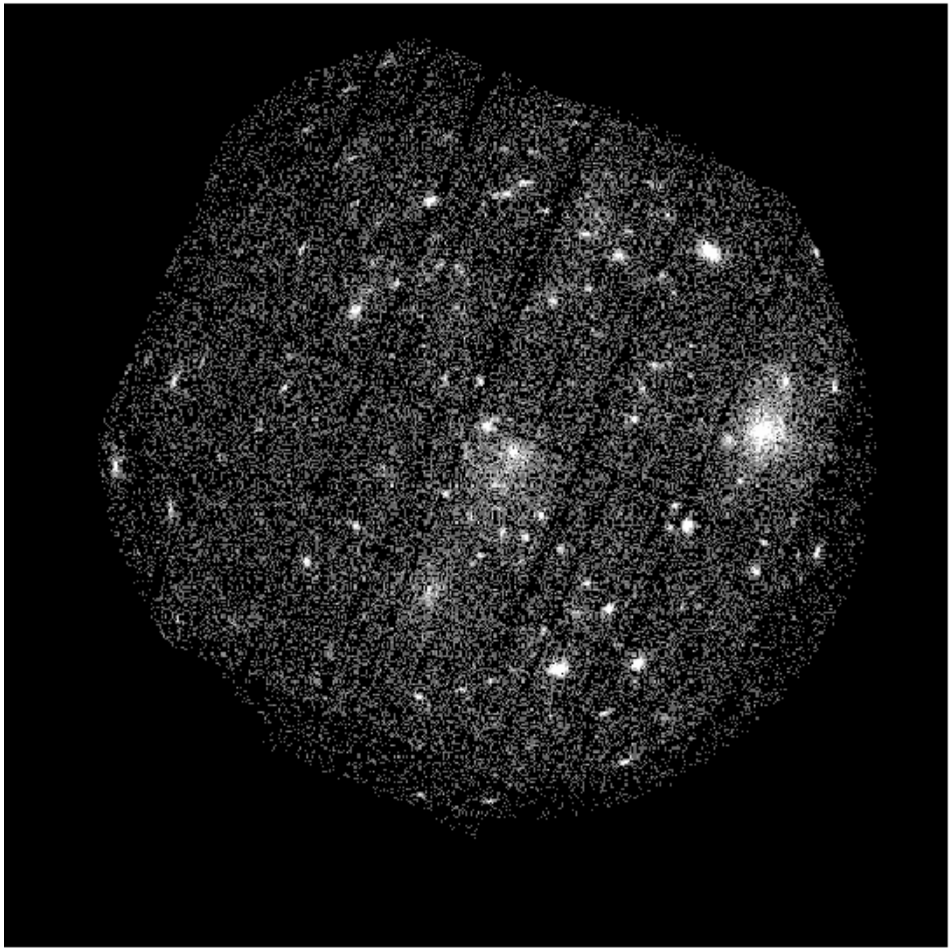
www.xcs-home.org

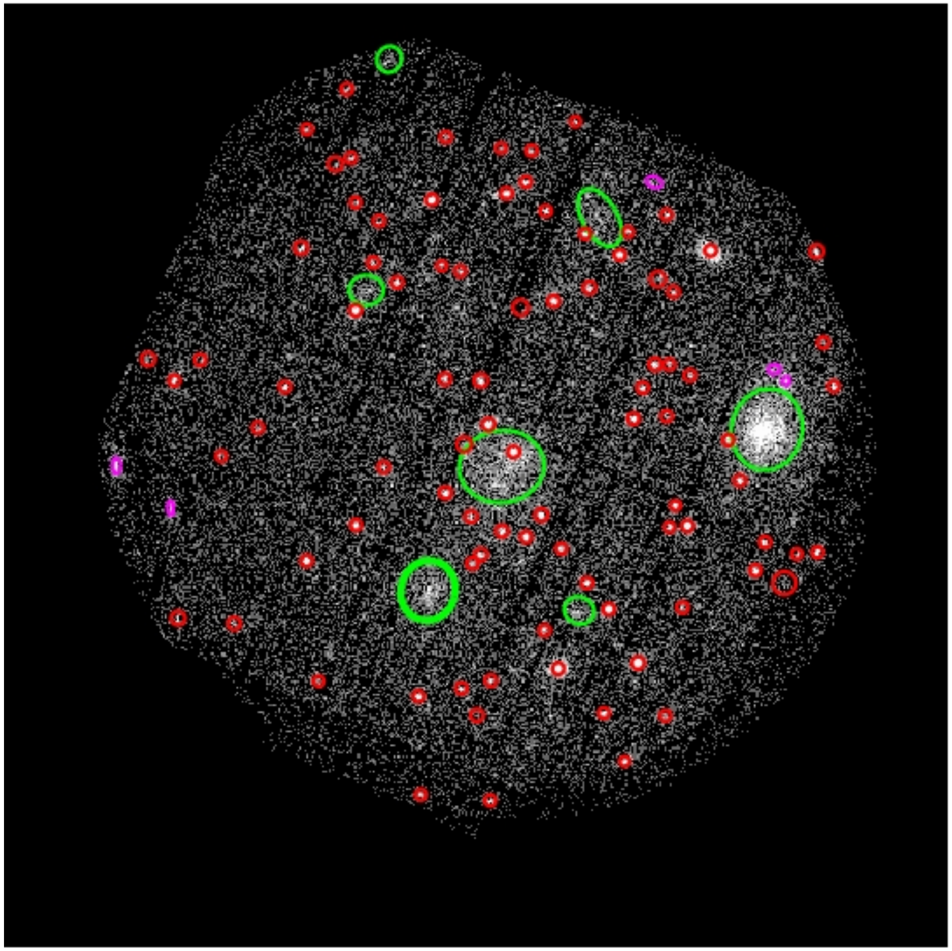
- The foremost objective of the XMM Cluster Survey (XCS) is to build a catalogue of serendipitous galaxy clusters, found using all the public data in the XMM-Newton Science Archive, and accurately determine their selection function.
- XCS has three main science goals:
  - To constrain cosmological parameters through the evolution of the cluster mass function with redshift
  - To study galaxy evolution in clusters
  - To determine how the properties of the cluster intergalactic medium change with time

X-ray Analysis

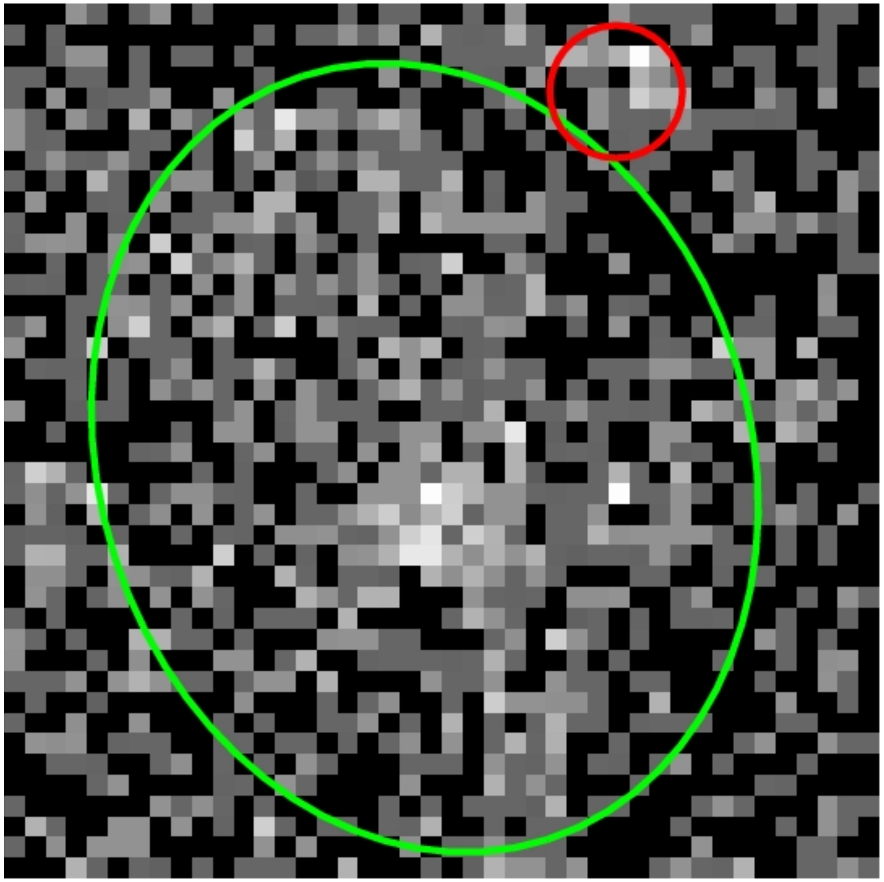
See Lloyd-Davies et al. – MNRAS 418, 14 (2011), arXiv:1010.0677

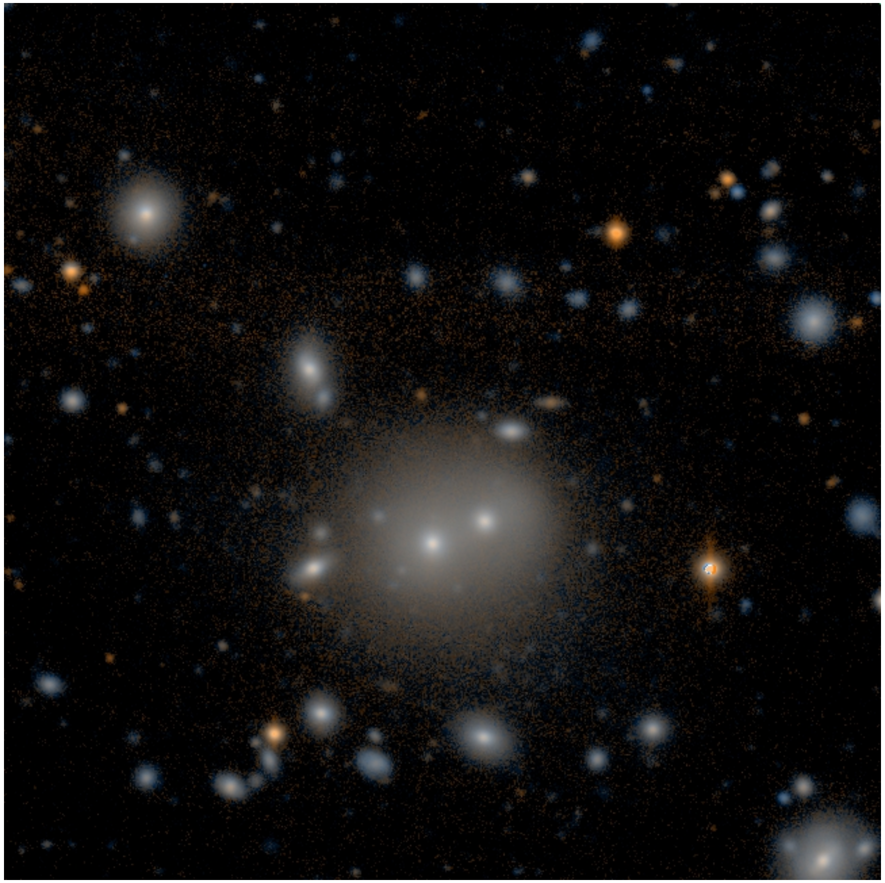
Excluding galactic plane (±20°), Magellanic clouds and XMM-Newton targeted clusters, the areas suitable for serendipitous cluster finding sum up to 410 deg^2 (280 deg^2 of which associated with exposures in excess of 10 ksecs), and yielded 3675 extended sources





As many cluster candidates as possible were then characterized through detailed checks of the literature and a Galaxy-Zoo style programme using data from SDSS-DR7, Stripe 82 co-add, and our own imaging/photo-z survey (NXS: NOAO-XCS Survey).





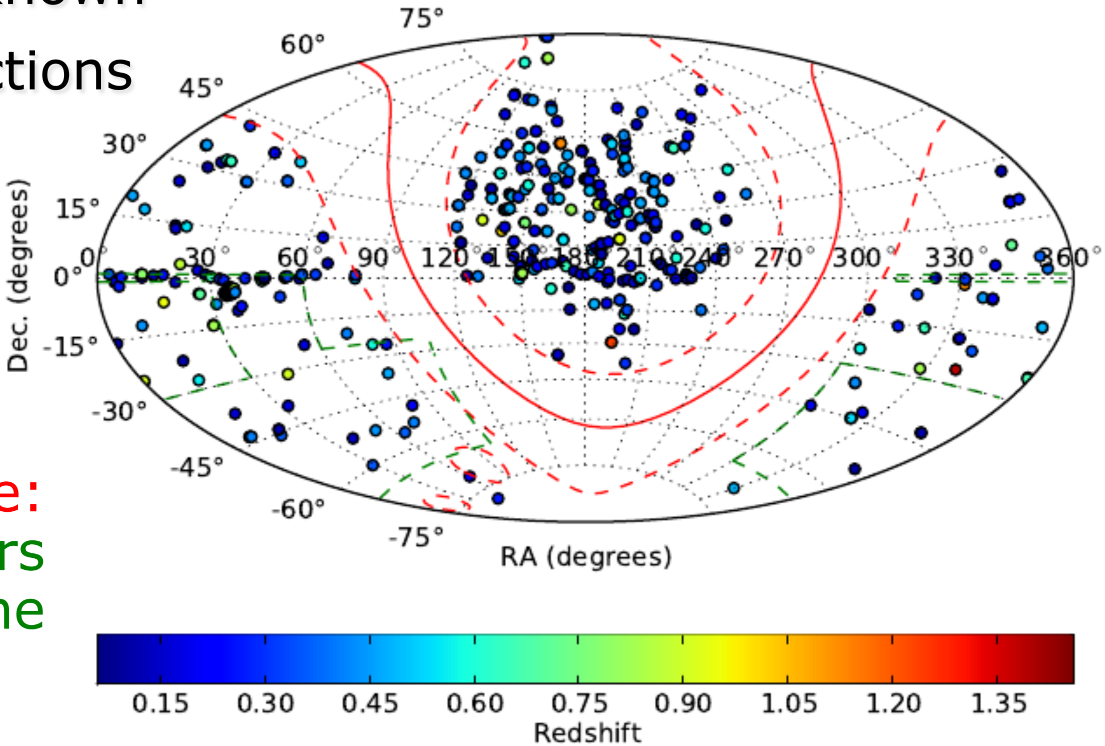
Finally, spectroscopic redshifts (261 - using Keck, Gemini, NTT and WHT data, from SDSS LRGs and from the literature), as well as photometric red-sequence redshifts (203 - using NXS, SDSS-DR7 and Stripe 82 data), were obtained whenever possible.

XCS Data Release 1

www.xcs-home.org/datareleases

See Mehrtens et al. (2012) – MNRAS in press, arXiv:1106.3056

- 503 optically confirmed X-ray groups and clusters, of which
  - 464 have redshift estimates ($0.06 < z < 1.46$)
  - 401 have temperature measurements ($0.4 < T_x < 14.7$ keV)
  - 256 were previously unknown
  - 357 are new X-ray detections of known clusters



Optical follow-up still incomplete: from 300 to 1700 groups/clusters waiting to be found among the orginal 3675 extended sources!

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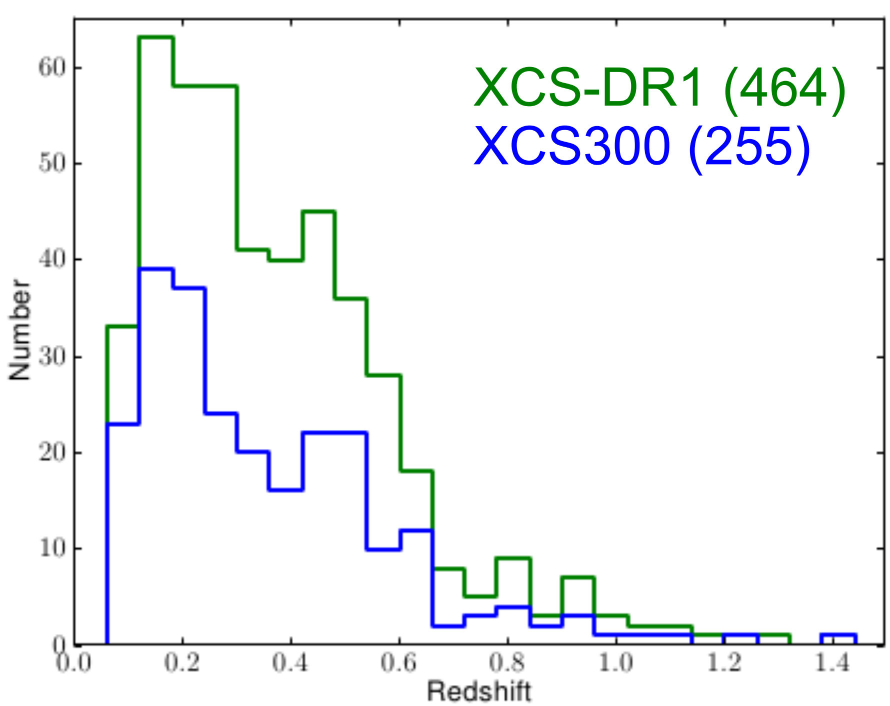
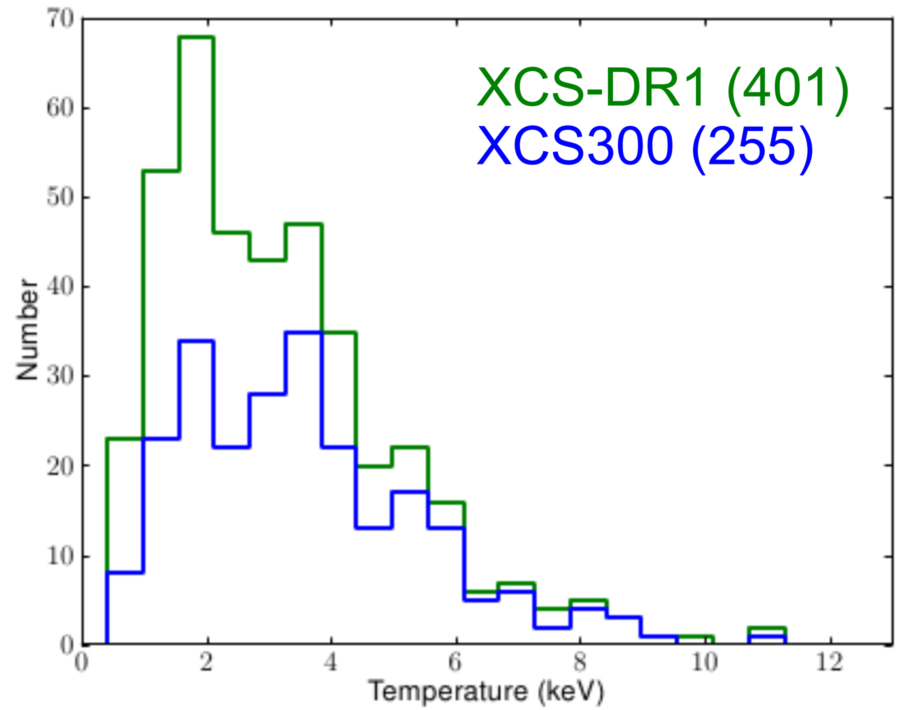
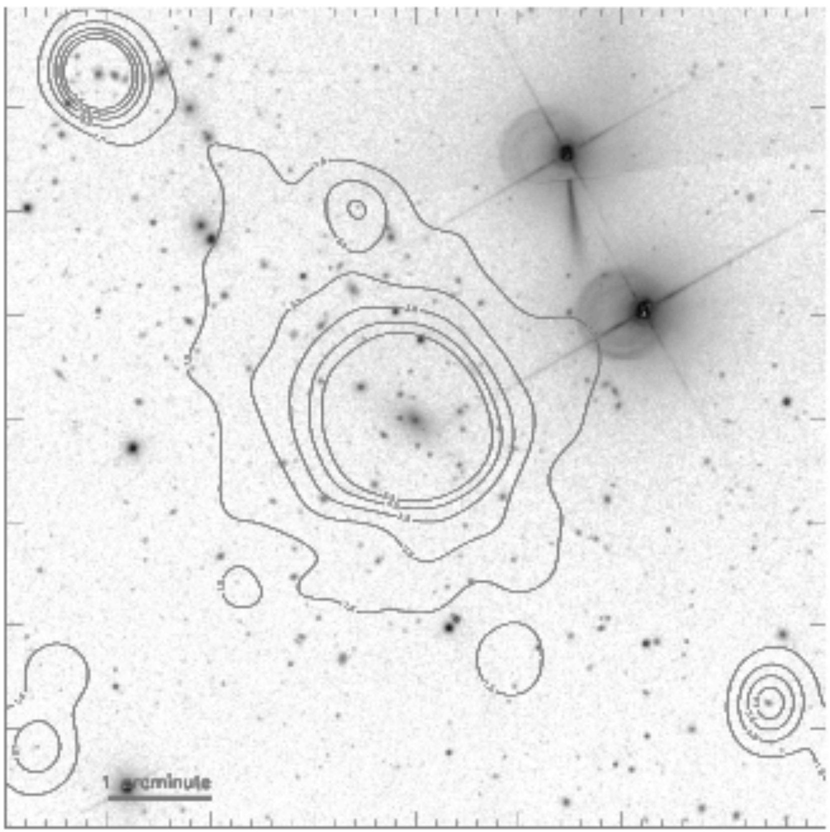




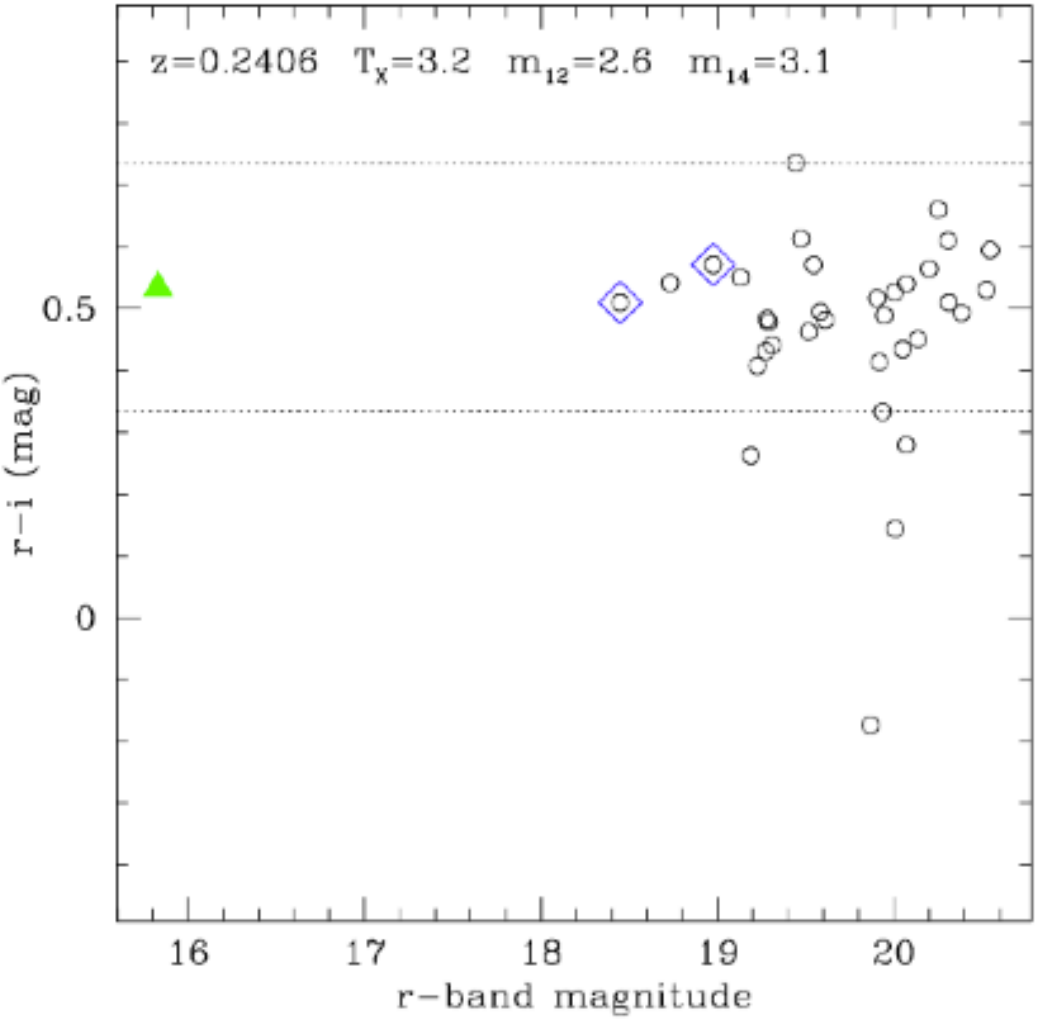
Fossil systems

17 XCS-DR1 systems with z < 0.25, selected using SDSS data, have been classified as **Fossil** (Ponman et al. 1994): their optical luminosity is dominated by a single galaxy. Some are not groups but clusters!

Harrison et al. – ApJ 752, 12 (2012), arXiv:1202.4450



XMMXCS J130749.6+292549.2

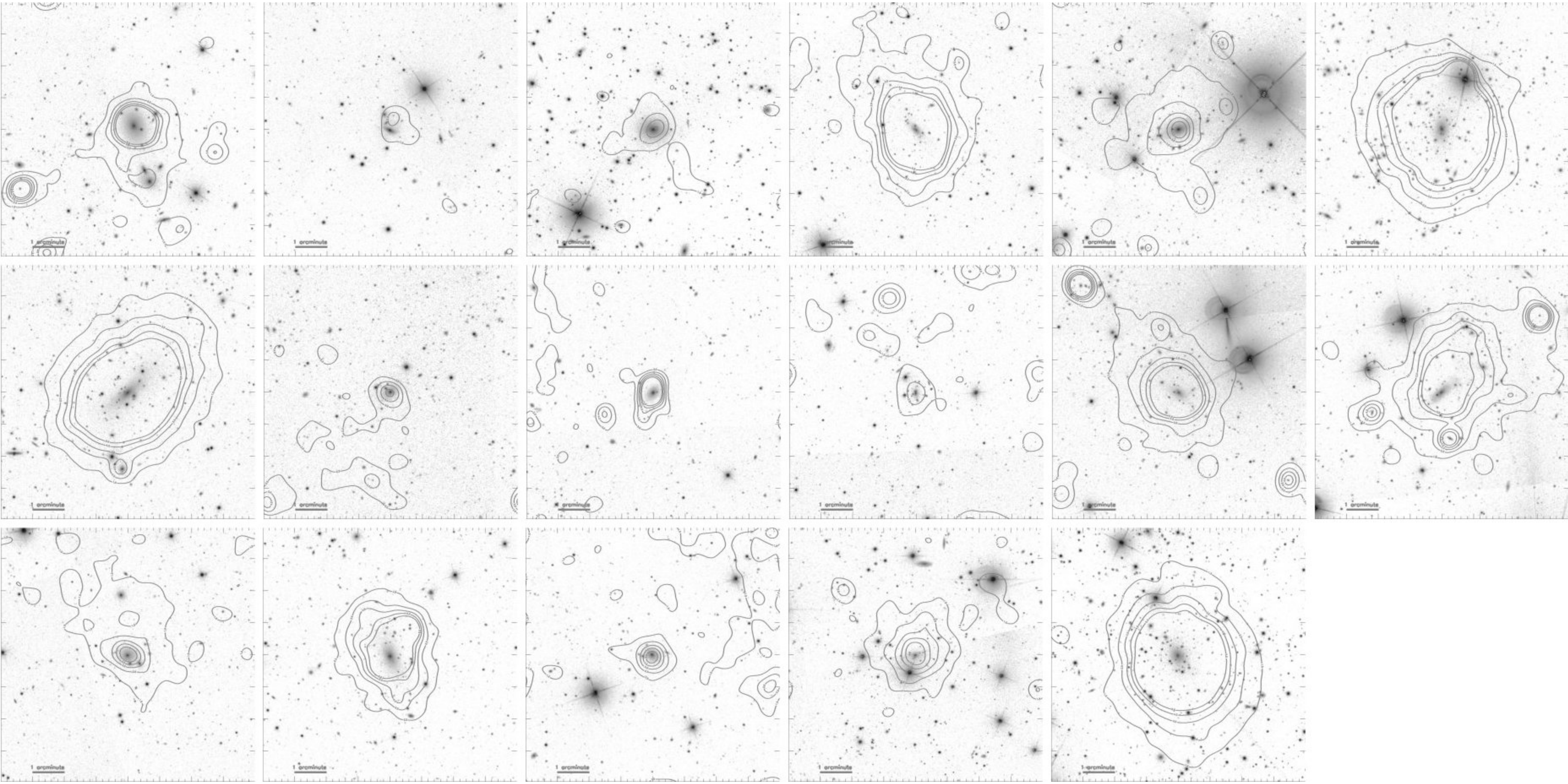


Fossil System Sample

ID	XCS Name	Literature name	Δm_{12}	Δm_{14}	R_{200}	T_X	L_X	L_{tot}	ΣL_{24}
1	XMMXCS J015315.0+010214.2	WHL J015315.2+010220	1.7±0.02	2.7±0.02	$0.664^{+0.007}_{-0.008}$	$1.08^{+0.02}_{-0.02}$	$0.05^{+0.11}_{-0.03}$	$3.06^{+0.06}_{-0.06}$	$0.57^{+0.06}_{-0.01}$
2	XMMXCS J030659.8+000824.9	SDSS CE J046.719402+00.163919	1.3±0.06	2.5±0.04	$1.01^{+0.27}_{-0.18}$	$2.3^{+1.3}_{-0.7}$	$0.014^{+0.020}_{-0.010}$	$1.05^{+0.03}_{-0.03}$	$0.29^{+0.03}_{-0.01}$
3	XMMXCS J073422.2+265143.9[a]	[DMM2008] IV	2.4±0.30	3.0±0.01(+0.5)	$0.67^{+0.10}_{-0.05}$	$1.1^{+0.2}_{-0.1}$	$0.21^{+0.79}_{-0.19}$	$2.86^{+0.74}_{-0.74}$	$0.41^{+0.09}_{-0.21}$
4	XMMXCS J083454.8+553420.9	WHL J083454.9+553421	2.4±0.03	3.0±0.03	$1.17^{+0.06}_{-0.07}$	$3.9^{+0.4}_{-0.4}$	$9.66^{+2.75}_{-2.74}$	$12.47^{+0.43}_{-0.29}$	$1.15^{+0.29}_{-0.03}$
5	XMMXCS J092540.0+362711.1	NSC J092521+362758	1.9±0.02	2.8±0.01(−0.3)	$1.14^{+0.12}_{-0.09}$	$3.0^{+0.6}_{-0.4}$	$1.03^{+0.87}_{-0.87}$	$4.53^{+0.23}_{-0.23}$	$0.61^{+0.26}_{-0.01}$
6	XMMXCS J101703.6+390250.7[a]	Abell 0963	2.2±0.02	2.7±0.02	$1.63^{+0.02}_{-0.02}$	$6.6^{+0.1}_{-0.1}$	$15.80^{+0.29}_{-0.25}$	$25.50^{+0.81}_{-0.81}$	$1.44^{+0.81}_{-0.03}$
7	XMMXCS J104044.4+395710.4	Abell 1068	2.3±0.02	3.1±0.03	$1.217^{+0.006}_{-0.006}$	$3.54^{+0.03}_{-0.03}$	$8.39^{+0.17}_{-0.16}$	$11.44^{+0.20}_{-0.20}$	$2.00^{+0.18}_{-0.03}$
8	XMMXCS J123024.3+111127.8	BLOX J1230.6+1113.3 ID	2.1±0.18	3.5±0.03	$0.54^{+0.01}_{-0.01}$	$0.80^{+0.03}_{-0.03}$	$0.018^{+0.002}_{-0.002}$	$1.61^{+0.06}_{-0.06}$	$0.39^{+0.06}_{-0.03}$
9	XMMXCS J123338.5+374114.9	—	2.6±0.01	3.2±0.02	$0.58^{+0.03}_{-0.04}$	$0.9^{+0.1}_{-0.1}$	$0.03^{+0.01}_{-0.01}$	$0.95^{+0.02}_{-0.02}$	$0.142^{+0.023}_{-0.003}$
10	XMMXCS J124425.9+164758.0[b]	WHL J124425.4+164756	0.5±0.20	2.3±0.10	$0.63^{+0.08}_{-0.06}$	$1.3^{+0.3}_{-0.2}$	$0.06^{+0.05}_{-0.03}$	$5.85^{+0.38}_{-0.38}$	$0.91^{+0.38}_{-0.11}$
11	XMMXCS J130749.6+292549.2	ZwCl 1305.4+2941	2.6±0.18	3.1±0.03	$1.04^{+0.03}_{-0.03}$	$3.2^{+0.2}_{-0.2}$	$1.94^{+0.10}_{-0.11}$	$12.83^{+0.40}_{-0.40}$	$1.12^{+0.23}_{-0.03}$
12	XMMXCS J131145.1+220206.0	MaxBCG J197.94248+22.02702	2.1±0.06	2.7±0.06	$1.16^{+0.06}_{-0.06}$	$3.4^{+0.2}_{-0.2}$	$1.57^{+0.69}_{-0.39}$	$10.97^{+0.29}_{-0.30}$	$1.39^{+0.28}_{-0.03}$
13	XMMXCS J134825.6+580015.8	—	2.0±0.02	2.6±0.02	$0.78^{+0.07}_{-0.05}$	$1.6^{+0.3}_{-0.2}$	$0.08^{+0.03}_{-0.04}$	$3.55^{+0.08}_{-0.08}$	$0.37^{+0.08}_{-0.01}$
14	XMMXCS J141627.7+231525.9[a]	ZwCl 1413.9+2330	1.8±0.02	2.9±0.02	$1.25^{+0.06}_{-0.06}$	$3.7^{+0.2}_{-0.2}$	$1.42^{+1.10}_{-0.51}$	$7.99^{+0.14}_{-0.14}$	$1.08^{+0.11}_{-0.02}$
15	XMMXCS J141657.5+231239.2	—	2.8±0.02	3.1±0.01	$0.56^{+0.04}_{-0.03}$	$0.9^{+0.1}_{-0.1}$	$0.017^{+0.005}_{-0.004}$	$1.51^{+0.04}_{-0.04}$	$0.171^{+0.035}_{-0.004}$
16	XMMXCS J160129.8+083856.3	—	2.4±0.03	3.1±0.03(−0.3)	$0.77^{+0.05}_{-0.04}$	$1.7^{+0.2}_{-0.2}$	$0.84^{+0.35}_{-0.35}$	$2.77^{+0.09}_{-0.09}$	$0.45^{+0.27}_{-0.07}$
17	XMMXCS J172010.0+263724.7[a]	SDSS-C4 3072	1.9±0.03	2.4±0.03	$1.54^{+0.01}_{-0.01}$	$5.53^{+0.04}_{-0.04}$	$21.58^{+23.45}_{-7.85}$	$18.64^{+1.26}_{-1.26}$	$1.94^{+1.26}_{-0.04}$

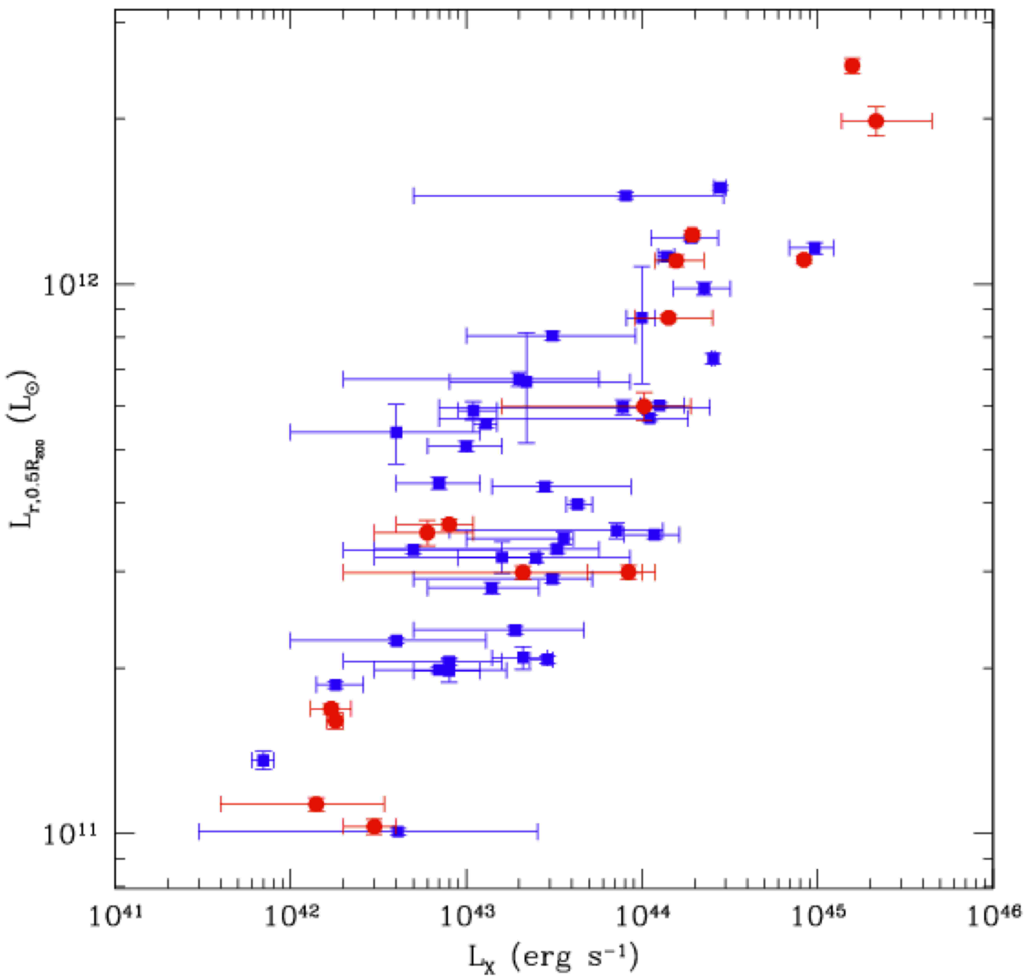
ID	SDSS Name	L_{gal}	σ	z	M_*	Age	Z	log(SSFR)
1	J015315.24+010220.6	1.81 ± 0.06	172.9	0.0597	0.47	10.4	0.030	−12.23
2	J030658.71+000833.2	0.69 ± 0.03	274.4	0.0751	0.29	10.5	0.030	−12.20
3	J073422.21+265144.9	1.88 ± 0.05	230.4	0.0796	0.82	8.1	0.032	−12.37
4	J083454.90+553421.1	6.69 ± 0.28	—	0.2412	—	—	—	—
5	J092539.05+362705.5	2.24 ± 0.06	266.3	0.1121	0.75	11.3	0.030	−12.31
6	J101703.63+390249.4	7.08 ± 0.21	317.0	0.2056	1.56	10.8	0.031	−12.70
7	J104044.49+395711.2	4.95 ± 0.17	—	0.1381	—	—	—	—
8	J123024.67+111122.8	1.27 ± 0.05	257.6	0.1169	0.37	10.9	0.021	−11.96
9	J123337.74+374122.0	0.81 ± 0.02	265.7	0.1023	0.33	11.8	0.026	−12.30
10	J124425.43+164756.9	3.64 ± 0.35	296.0	0.2346	0.52	11.8	0.027	−12.29
11	J130749.23+292548.2	6.71 ± 0.22	325.9	0.2406	1.36	10.9	0.028	−12.13
12	J131146.19+220137.2	4.36 ± 0.26	224.6	0.1715	0.97	9.5	0.027	−12.13
13	J134825.78+580018.7	2.35 ± 0.07	206.6	0.1274	0.59	8.5	0.033	−11.77
14	J141627.37+231522.5	3.53 ± 0.10	282.2	0.1382	1.08	9.9	0.032	−12.29
15	J141657.46+231242.5	1.27 ± 0.03	233.1	0.1159	0.42	8.7	0.033	−11.26
16	J160129.75+083850.6	1.71 ± 0.06	237.0	0.1875	1.02	11.3	0.028	−12.50
17	J172010.04+263732.0	5.40 ± 0.18	308.3	0.1596	0.92	5.6	0.031	−11.44

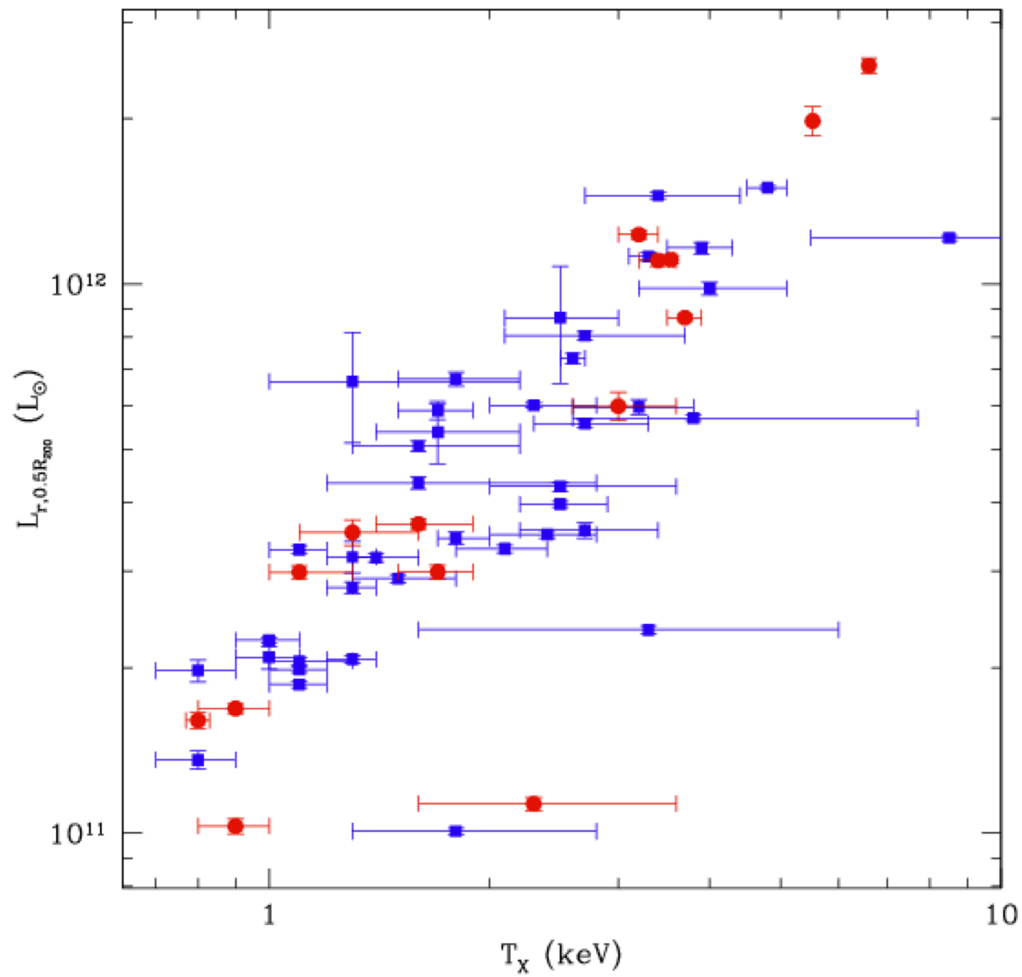
Fossil System Sample



XMM-Newton X-ray flux contours overlaid on SDSS DR7 data

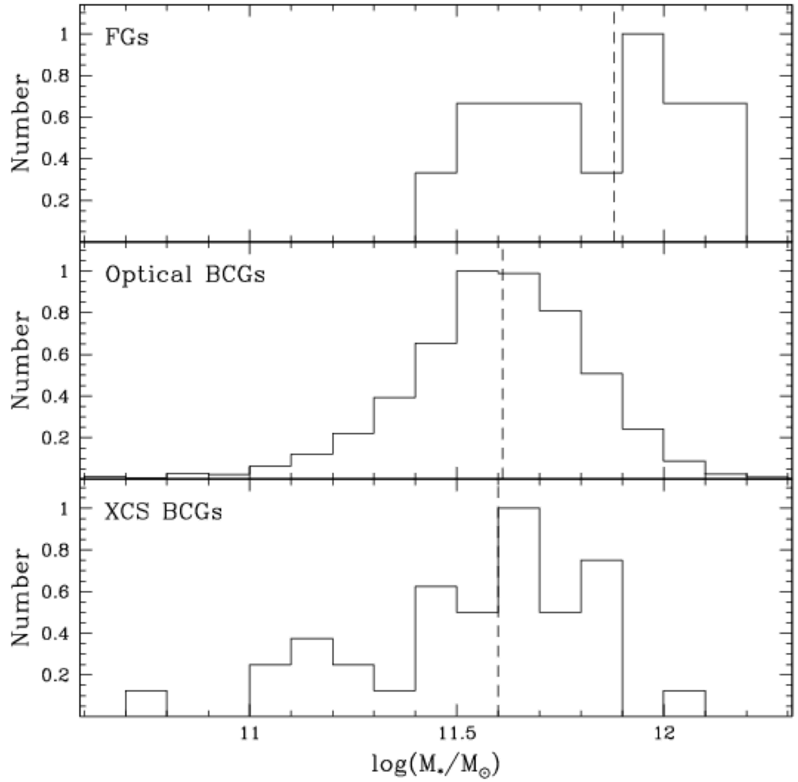
Fossil systems

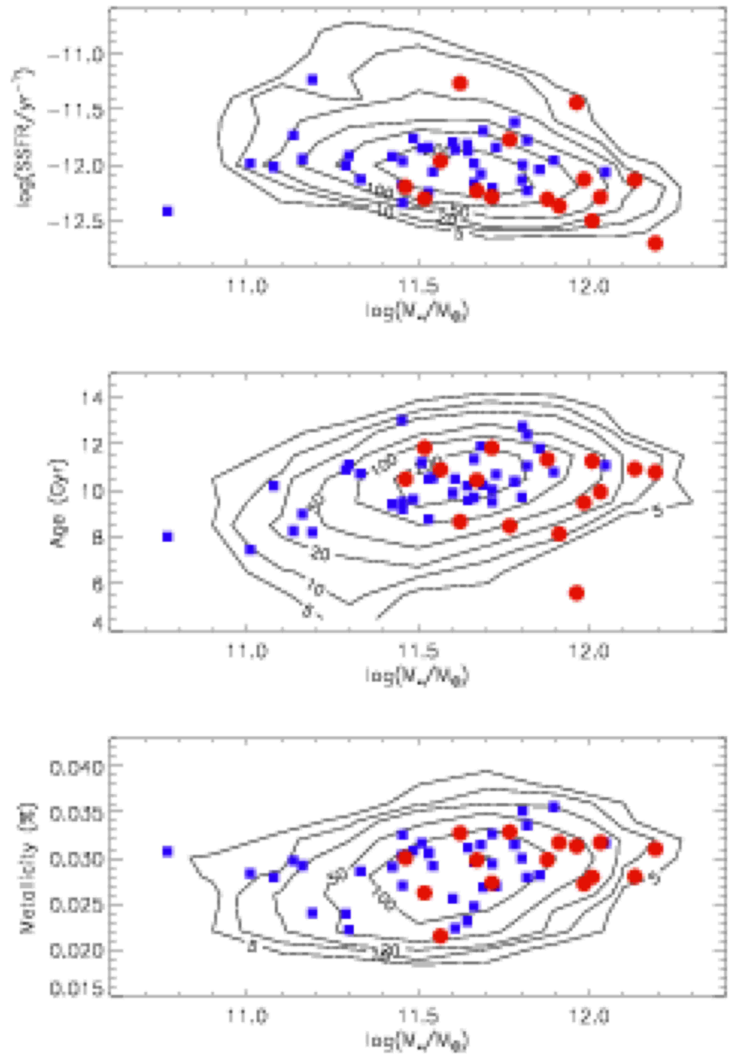




The fossil systems follow the same optical to X-ray scaling relations of the general population of galaxy groups and clusters.

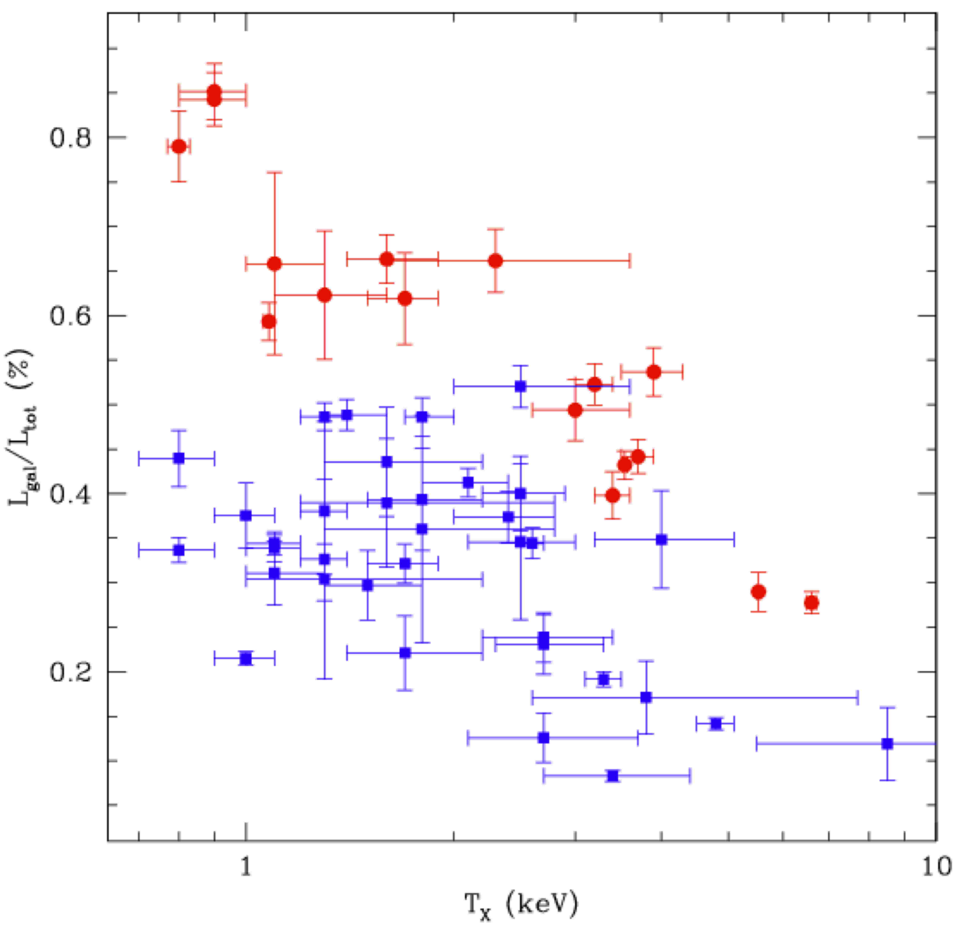
Fossil systems

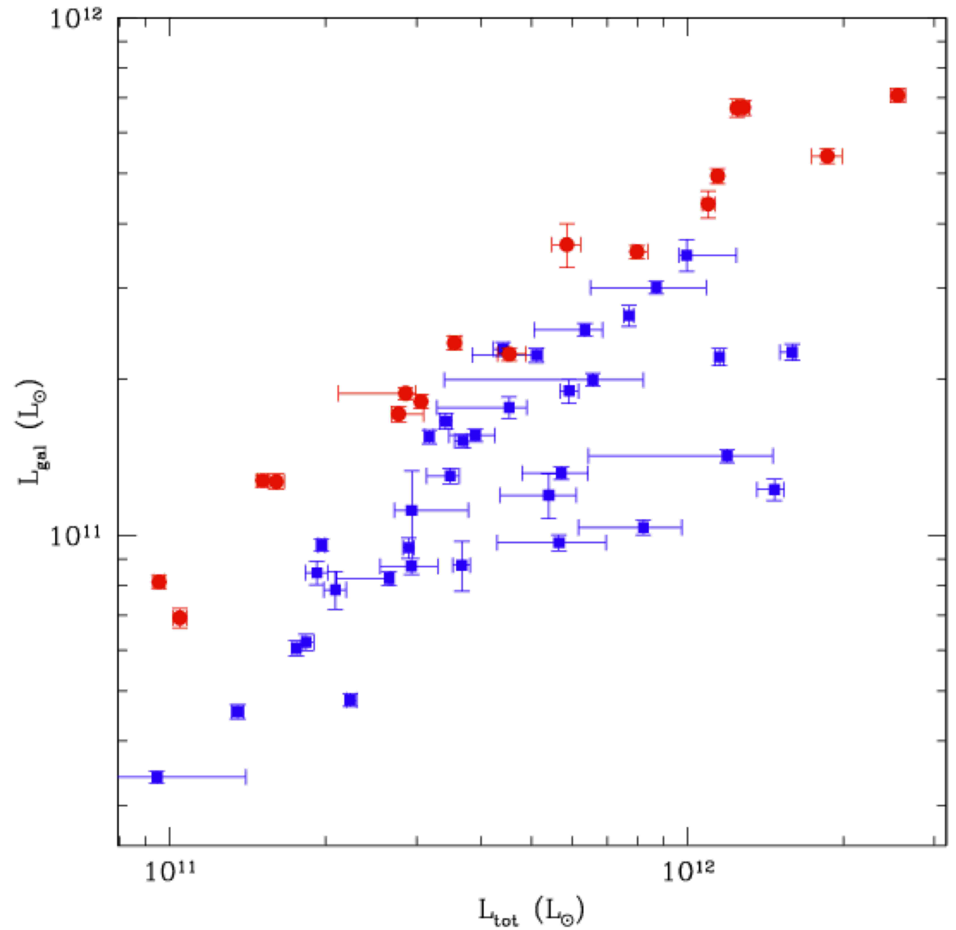




The brightest galaxies in fossil systems have star-formation histories, stellar populations and metalicities which are similar to normal brightest cluster galaxies. But, at fixed group/cluster mass, the stellar masses of the fossil galaxies are larger compared to normal brightest cluster galaxies.

Fossil systems





Moreover, the fossil galaxies are found to contain a significant fraction of the total optical luminosity of the system within $0.5R_{200}$, as much as 85%, compared to the non-fossils, which can have as little as 10%. Our results support the hypothesis that fossil systems formed early and in the highest density regions of the Universe and that fossil galaxies represent the end products of galaxy mergers in groups and clusters.

XCS – Planck overlap

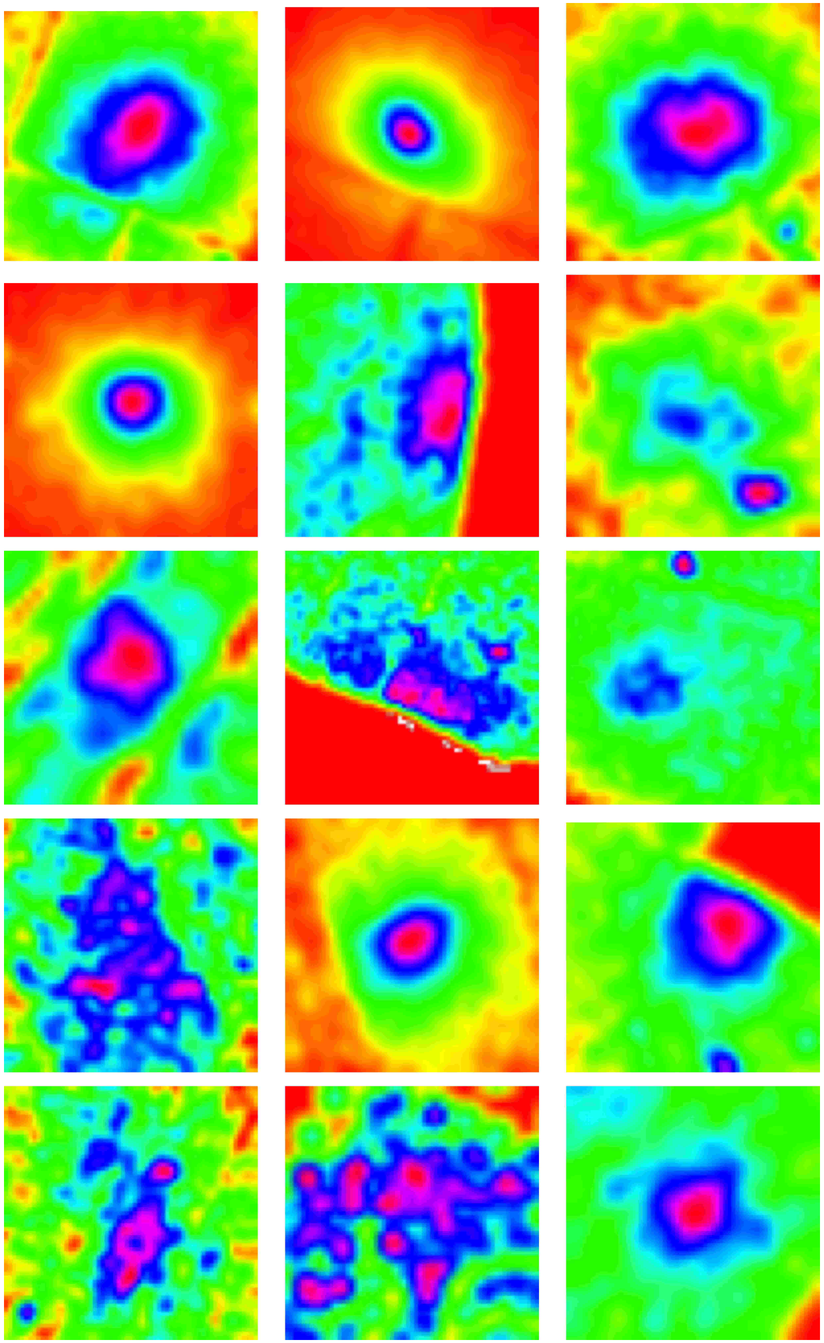
In Viana et al. – MNRAS 422, 1007 (2012), arXiv:1109.1828 – we identified 15 XCS-DR1 galaxy clusters expected to be detected by Planck (three of which are already present in the Planck ESZ catalogue).

Cluster ID	Alternative name	z	$L^d_{\rm bol}$	$L_{\rm bol}$	$T^d_{\rm X}$	$T_{\rm X}$	Y
XMMXCS J151618.6+000531.3	MaxBCG J229.07472+00.08903	0.12	$4.4^{+0.1}_{-0.1}$	$4.4^{+0.1}_{-0.1}$	$5.4^{+0.1}_{-0.1}$	$5.3^{+0.1}_{-0.1}$	$0.3^{+0.1}_{-0.1}$
XMMXCS J104044.4+395710.4	ABELL 1068	0.14	$8.4^{+0.2}_{-0.2}$	$8.2^{+0.2}_{-0.2}$	$3.5^{+0.1}_{-0.1}$	$3.6^{+0.1}_{-0.1}$	$0.4^{+0.1}_{-0.1}$
XMMXCS J030348.3−775241.3* ●	1RXS J030344.4−775222	0.27	$16.2^{+0.4}_{-0.4}$	$16.3^{+0.3}_{-0.4}$	$8.7^{+0.3}_{-0.3}$	$8.3^{+0.3}_{-0.3}$	$1.0^{+0.2}_{-0.1}$
XMMXCS J122658.1+333250.9	WARP J1226.9+3332	0.89	$47.9^{+1.2}_{-1.1}$	$47.6^{+1.1}_{-1.1}$	$11.1^{+0.5}_{-0.5}$	$11.4^{+0.4}_{-0.4}$	$1.8^{+0.3}_{-0.2}$
XMMXCS J133254.8+503153.1* ●	RBS 1283	0.28	$12.5^{+0.4}_{-3.7}$	$12.7^{+0.3}_{-0.2}$	$7.7^{+0.3}_{-0.4}$	$7.3^{+0.4}_{-0.3}$	$0.8^{+0.1}_{-0.1}$
XMMXCS J111515.6+531949.5	SDSS J1115+5319 CLUSTER	0.47	$20.5^{+0.1}_{-0.1}$	$20.5^{+0.1}_{-0.1}$	$5.4^{+1.5}_{-0.9}$	$8.3^{+0.4}_{-0.4}$	$1.1^{+0.2}_{-0.2}$
XMMXCS J090101.5+600606.2	MaxBCG J135.25325+60.10133	0.29	$19.1^{+3.9}_{-3.2}$	$16.7^{+3.1}_{-2.8}$	$5.9^{+2.9}_{-1.4}$	$7.7^{+0.6}_{-0.6}$	$1.0^{+0.2}_{-0.2}$
XMMXCS J113020.3−143629.7* ●	ABELL 1285	0.11	$5.7^{+4.5}_{-1.7}$	$4.5^{+1.1}_{-1.0}$	$5.4^{+0.7}_{-0.7}$	$5.0^{+0.5}_{-0.4}$	$0.3^{+0.1}_{-0.1}$
XMMXCS J033049.7−522836.5	ABELL 3128 NE	0.44	$20.9^{+0.2}_{-0.2}$	$20.9^{+0.1}_{-0.1}$	$4.5^{+0.1}_{-0.1}$	$4.9^{+0.1}_{-0.1}$	$0.8^{+0.1}_{-0.1}$
XMMXCS J021440.9−043321.9	ABELL 0329	0.14	$2.8^{+3.4}_{-1.6}$	$3.1^{+0.6}_{-0.5}$	$4.5^{+0.1}_{-0.1}$	$4.5^{+0.1}_{-0.2}$	$0.2^{+0.1}_{-0.1}$
XMMXCS J004624.5+420429.5	RX J0046.4+4204	0.30	$7.0^{+0.3}_{-0.3}$	$7.0^{+0.3}_{-0.3}$	$6.9^{+0.6}_{-0.6}$	$6.0^{+0.3}_{-0.3}$	$0.5^{+0.1}_{-0.1}$
XMMXCS J141832.3+251104.9	WARP J1418.5+2511	0.29	$6.3^{+0.5}_{-0.5}$	$6.4^{+0.4}_{-0.5}$	$6.4^{+0.4}_{-0.4}$	$5.9^{+0.3}_{-0.3}$	$0.4^{+0.1}_{-0.1}$
XMMXCS J123019.6+161634.1	NSC J123020+161652	0.20	$4.6^{+0.8}_{-0.7}$	$4.0^{+0.7}_{-0.5}$	$4.3^{+0.6}_{-0.5}$	$4.7^{+0.4}_{-0.3}$	$0.3^{+0.1}_{-0.1}$
XMMXCS J121744.6+472921.5	400d J1217+4729	0.27	$23.2^{+13.2}_{-10.9}$	$8.4^{+6.1}_{-3.4}$	$9.8^{+6.6}_{-3.7}$	$6.1^{+1.3}_{-1.0}$	$0.5^{+0.4}_{-0.2}$
XMMXCS J095343.6+694735.0	400d J0953+6947	0.21	$1.0^{+3.0}_{-0.7}$	$3.6^{+1.7}_{-1.3}$	$5.7^{+1.1}_{-0.7}$	$4.7^{+0.6}_{-0.5}$	$0.3^{+0.1}_{-0.1}$

$$P(L_{bol} \mid L^d_{bol}) \, \alpha \, P(L^d_{bol} \mid L_{bol}) P(L_{bol}), \quad P(T_X \mid T^d_X) \, \alpha \, P(T^d_X \mid T_X) P(T_X)$$

XCS – Planck overlap

- At z ≈ 0.1, almost 90% of the galaxy clusters expected to be detected by Planck will also be detected by XCS (with more than 50 photon counts), slowly decreasing to slightly more than 70% at z ≈ 1 (due to the existence of observations with low exposure times in the XMM-Newton archive).
- The XCS will not only be able to help better characterize the sensitivity of the Planck Cluster Survey, which is essential in order to recover the scaling relations pertaining to the underlying galaxy cluster population, but will also enable Planck to recover some information on many of the galaxy clusters that are just below its detection threshold in the sky area that is common to both surveys.

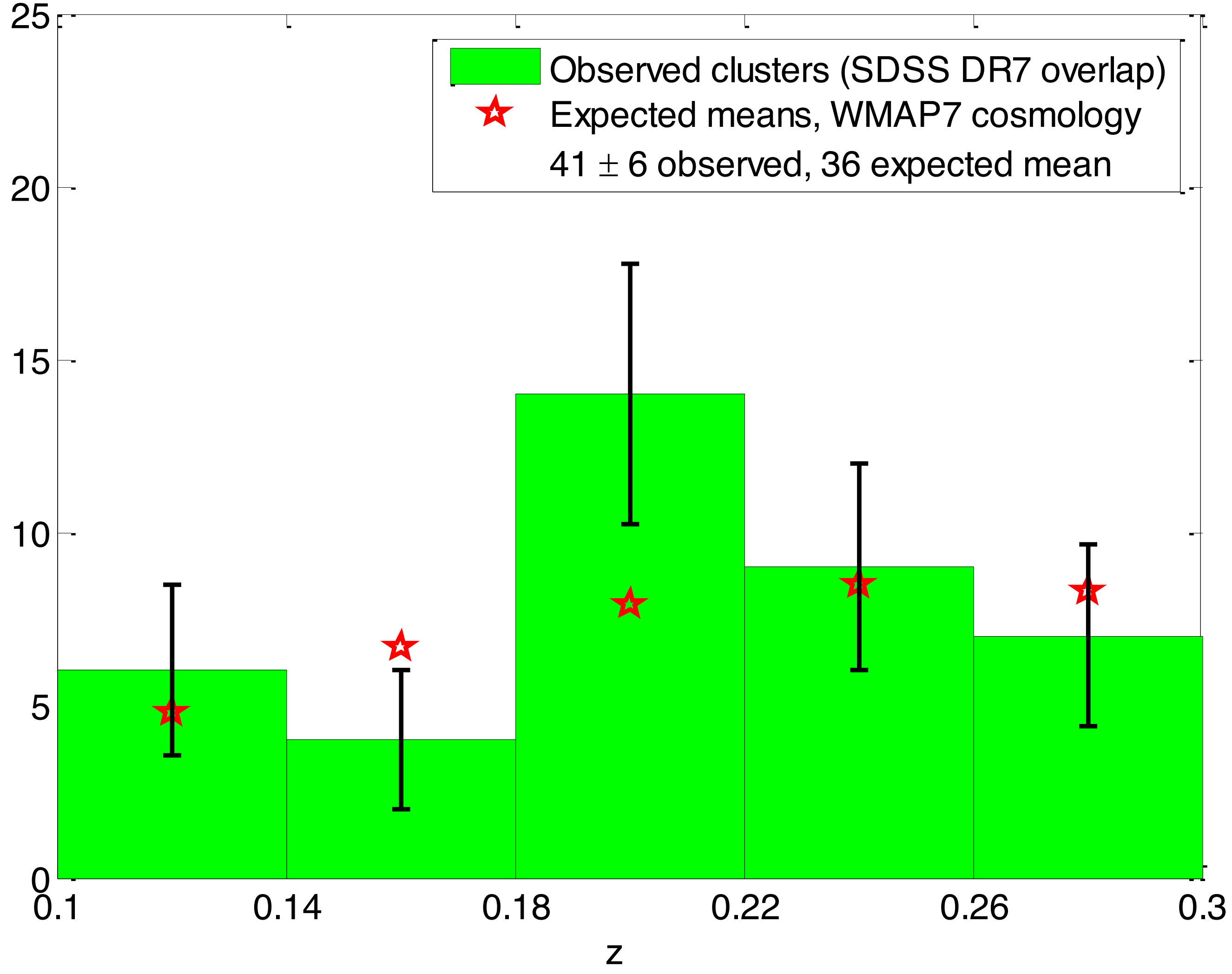


First comparison:
SDSS DR7—XCS-DR1 overlap

Stockholms universitet

0.1 < z < 0.3
T > 2 keV
>300 counts
121 sq. deg.

Measurement errors ignored



Sahlen et al. in prep.

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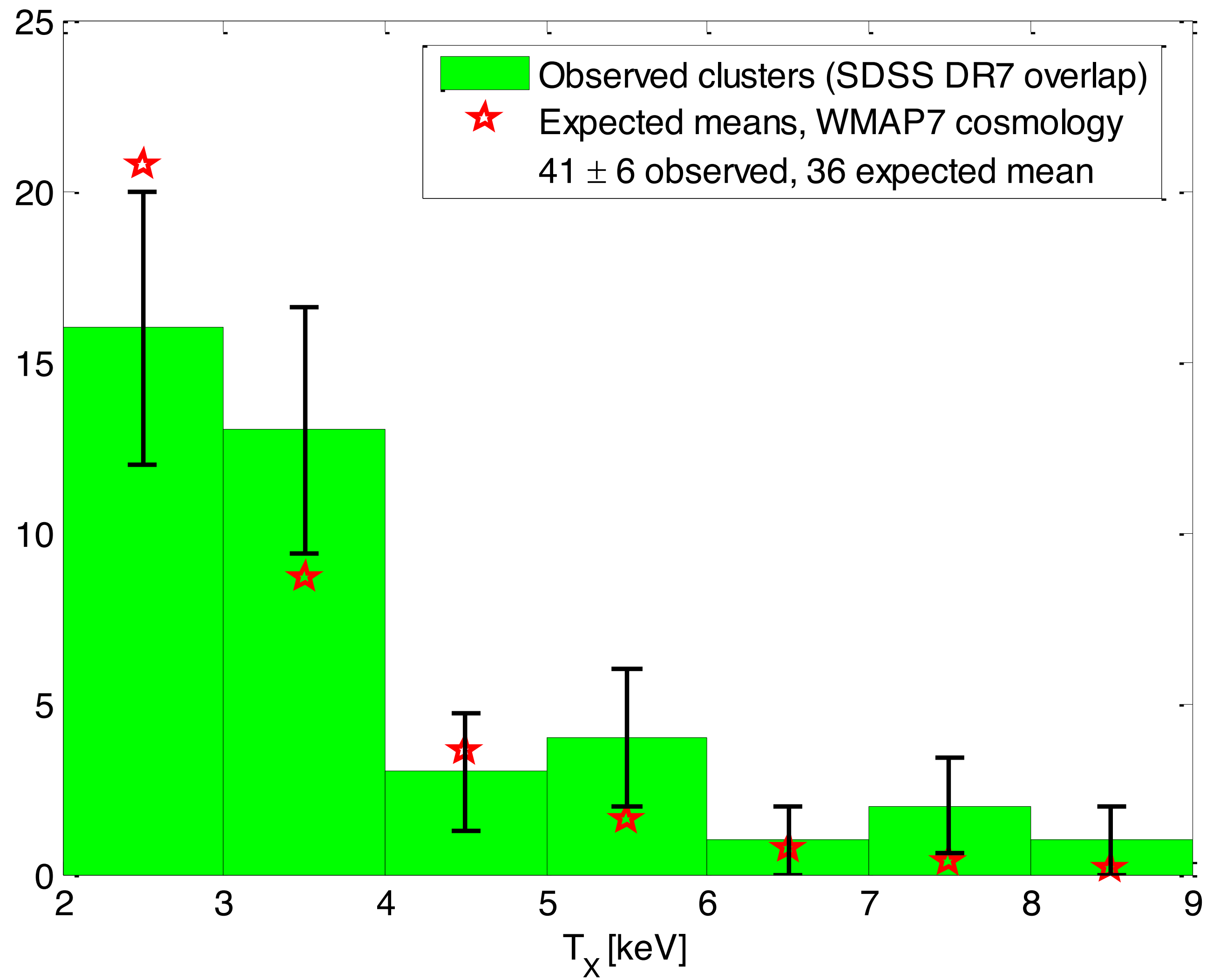


Sahlen et al. in prep.

XCS Update

- **Image pipeline:** re-calibrated and updated to the latest version of SAS, and in the process of being used to produce new images for all the ObsIDs in the public XMM-Newton archive.

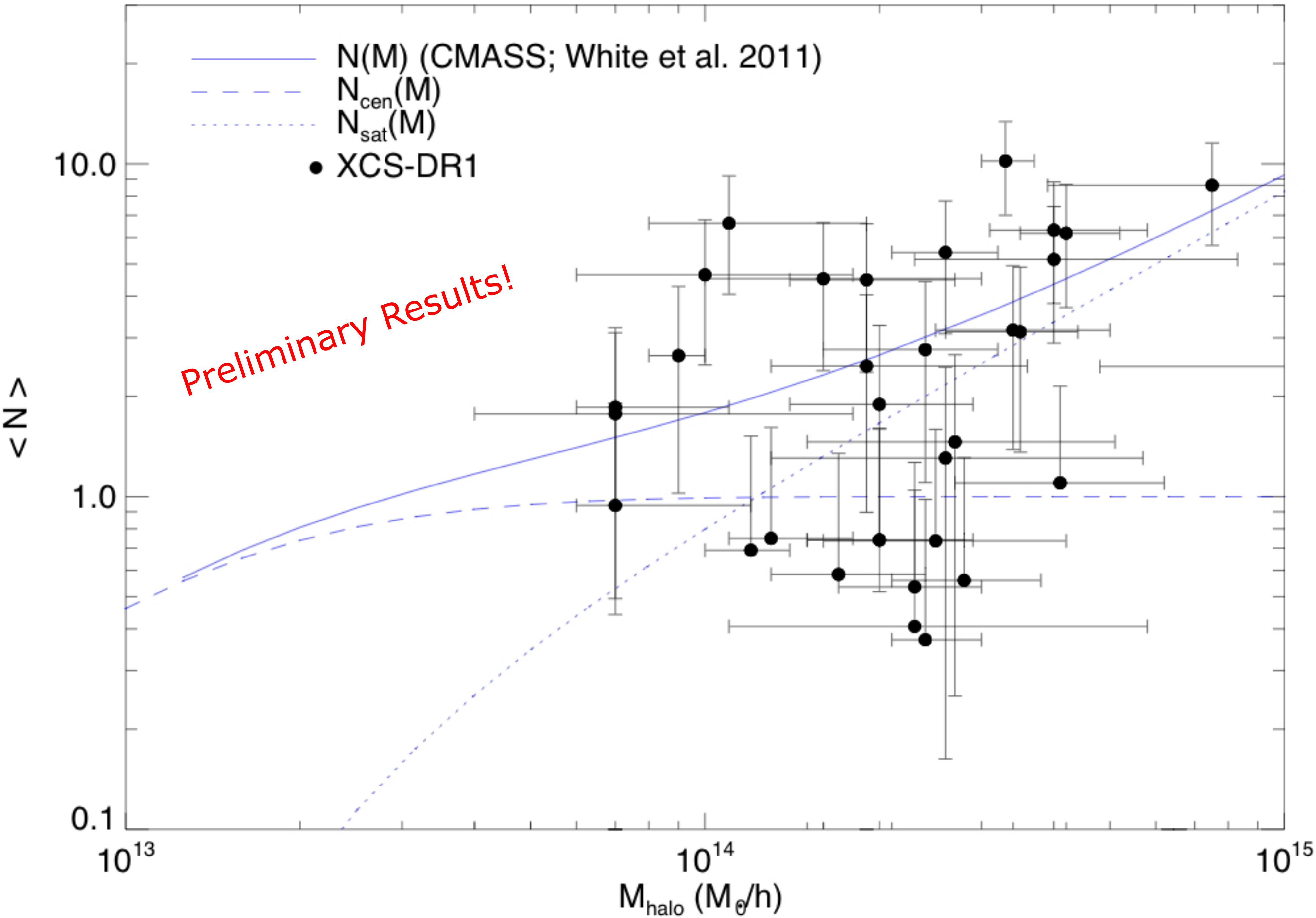
- **Image masking:** high background regions, as well as regions contaminated by flux from target clusters and non-cluster extended sources, are now more efficiently removed, which will reduce the number of false cluster detections when we re-apply our source finding algorithm (XAPA), to all the ObsIDs in the public XMM-Newton archive.

- **Source detection:** another (larger) wavelet scale has been added to XAPA cut down on false cluster detections and to allow us to analyze (nearby, very extended) XMM-Newton target clusters.

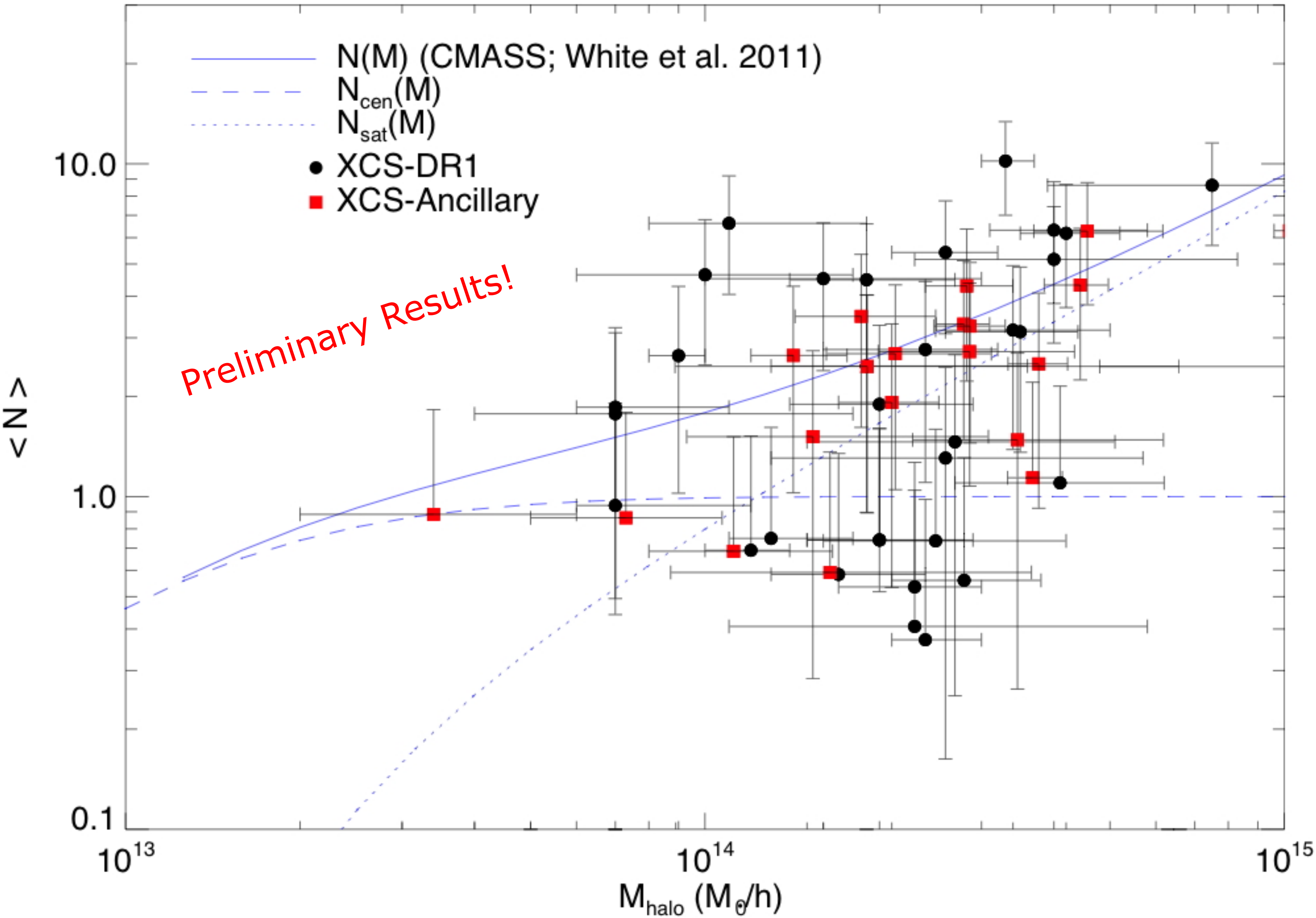
XCS Update

- **Source characterization:** all NED clusters in the XMM-SDSS joint footprint have been checked to see if they coincide with an XCS candidate; the same will soon be done for the rest of the sky and for cluster catalogues too recent to be included in NED. This will not only enable the confirmation of new serendipitous detections (of already known clusters), but will also allow us to build a database of ***XCS-Ancillary*** target clusters with hundreds of entries, which will be useful for a variety of science studies were knowledge of the cluster selection function is not a critical issue, e.g. measurements of halo occupation numbers (using BOSS galaxies - ongoing) and optical to X-ray correlations (ongoing). We will soon be extending our XCS-Zoo identification programme using additional imaging data from CFHTLS, RCS and VHS (and later from DES and maybe Pan-STARRS).

Mehrtens et al. in prep.



Mehrtens et al. in prep.



XCS Update

- **Redshift measurements:** a new non-parametric method to estimate photometric redshifts has been developed (based on measuring galaxy redshifts rather than red sequence redshifts), and will soon be applied to XCS cluster candidates in the SDSS DR8 footprint; ongoing spectroscopic redshift campaigns using multi-object spectroscopy at Gemini and Magellan; eventually, DES (and possibly Pan-STARRS) data will be used to estimate photometric redshifts, which will enable the measurement of X-ray temperatures for at least 200 XCS galaxy clusters.

- **Spectroscopy pipeline:** now keeps a record of all fits, including for the IGM metal abundance, using both Cash and Chi-Squared statistics.

- **Selection function:** will be re-calculated as a function of cluster observables, like flux, temperature, redshift and angular size, for each ObsID (rather than for a typical XMM-Newton ObsID).

Summary

- XCS-DR1 is presently the largest homogeneous sample of galaxy clusters with X-ray temperature estimates, reaches to $z \sim 1.5$, and spans a wide range in mass, from the largest clusters to groups:

  503 optically confirmed X-ray groups and clusters, of which

    - 464 have redshift estimates ($0.06 < z < 1.46$)
    - 401 have temperature measurements ($0.4 < T_x < 14.7$ keV)
    - 256 were previously unknown
    - 357 are new X-ray detections of known clusters

www.xcs-home.org/datareleases

- We are already working towards XCS-DR2!