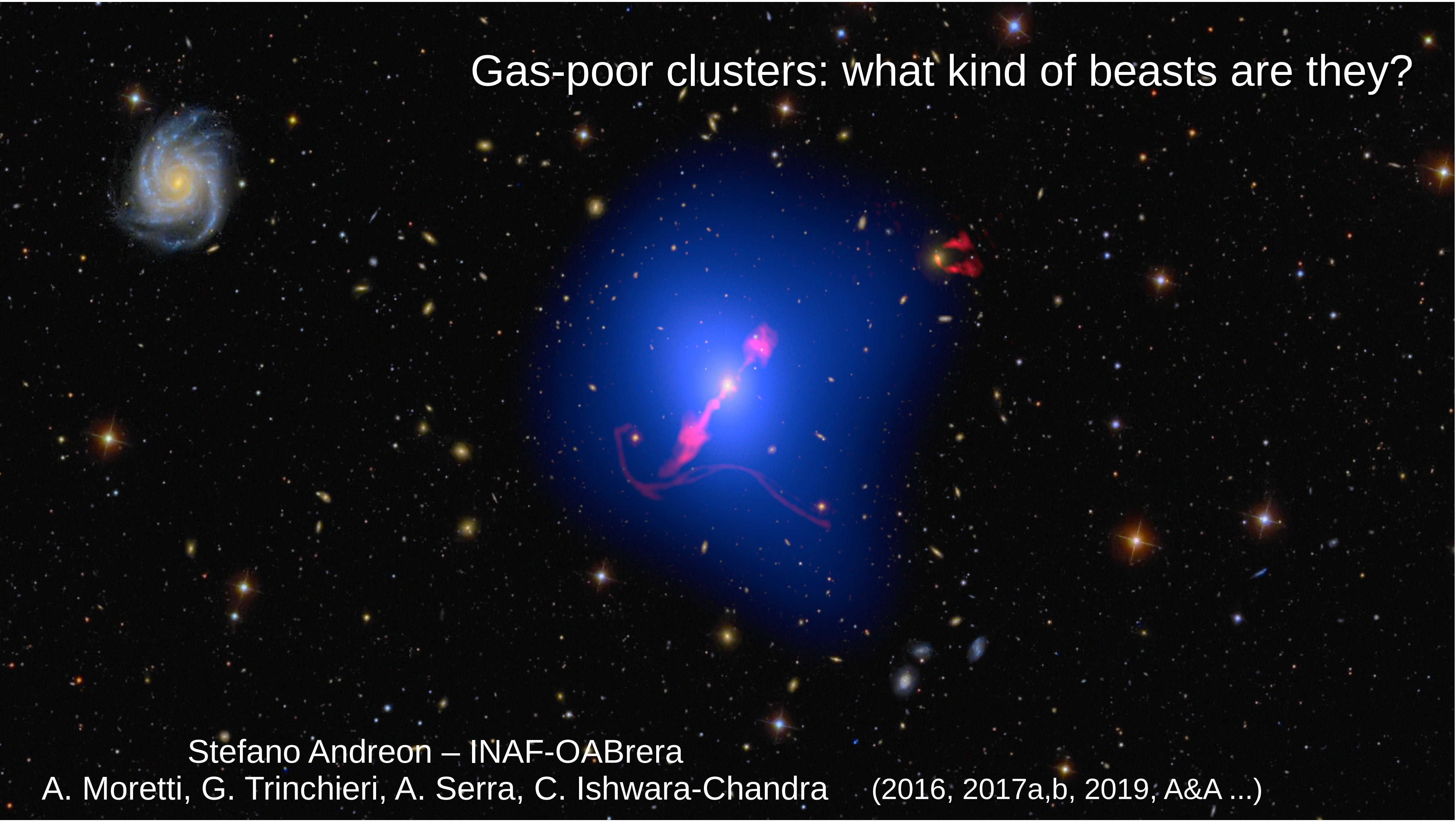
Gas-poor clusters: what kind of beasts are they?



Stefano Andreon – INAF-OABrera
A. Moretti, G. Trinchieri, A. Serra, C. Ishwara-Chandra

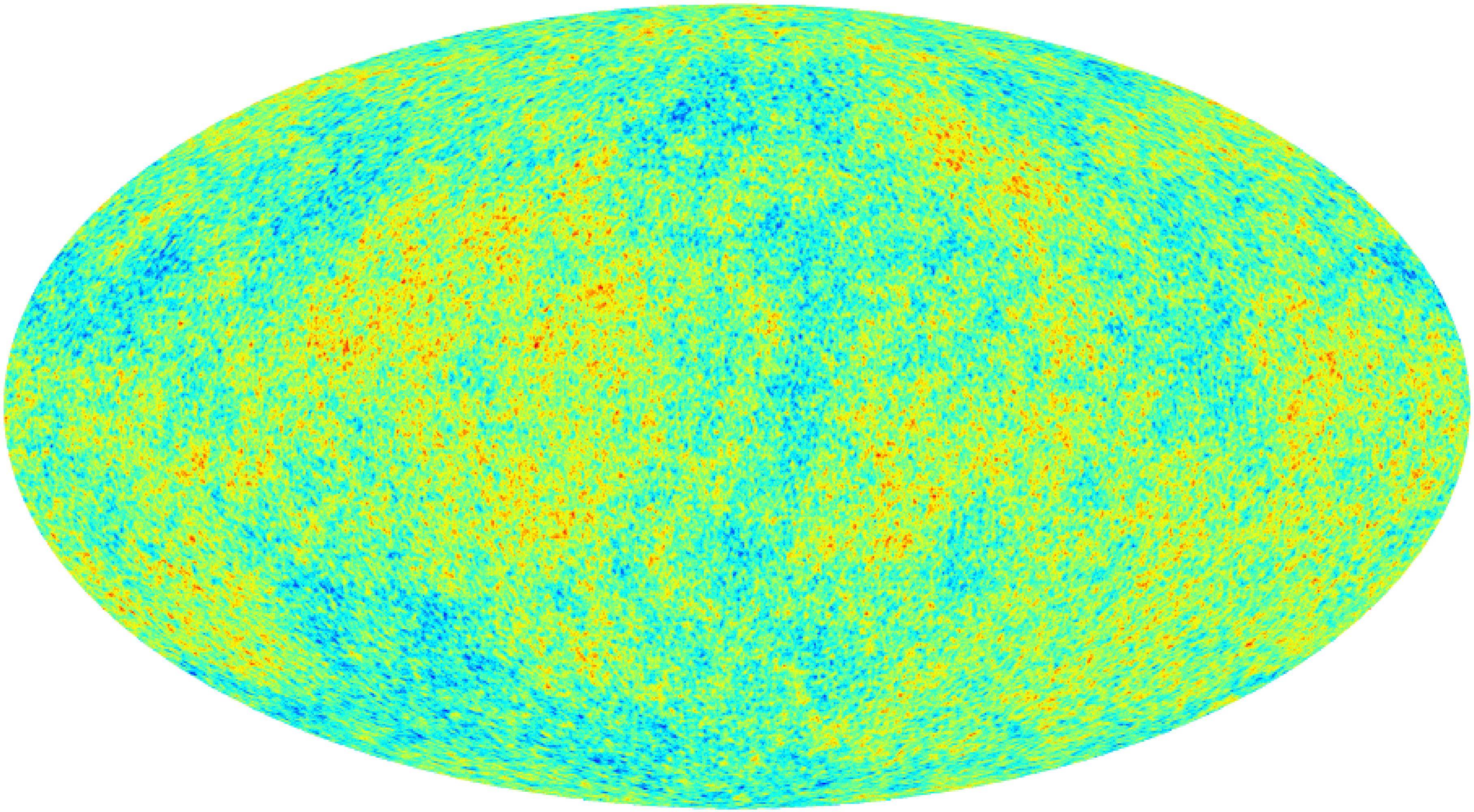
(2016, 2017a,b, 2019, A&A ...)

Plan of this talk

- Introduction on clusters
- Is our view of clusters biased? Just a little, or more than believed? The community is changing idea now.
- A first ICM-unbiased survey (with an old pathfinder)
- One easily-missed cluster, CL2015, under the microscope
- More are coming … including at z~2!

Lux facta est

0.4 Myr after BB (z~1000)



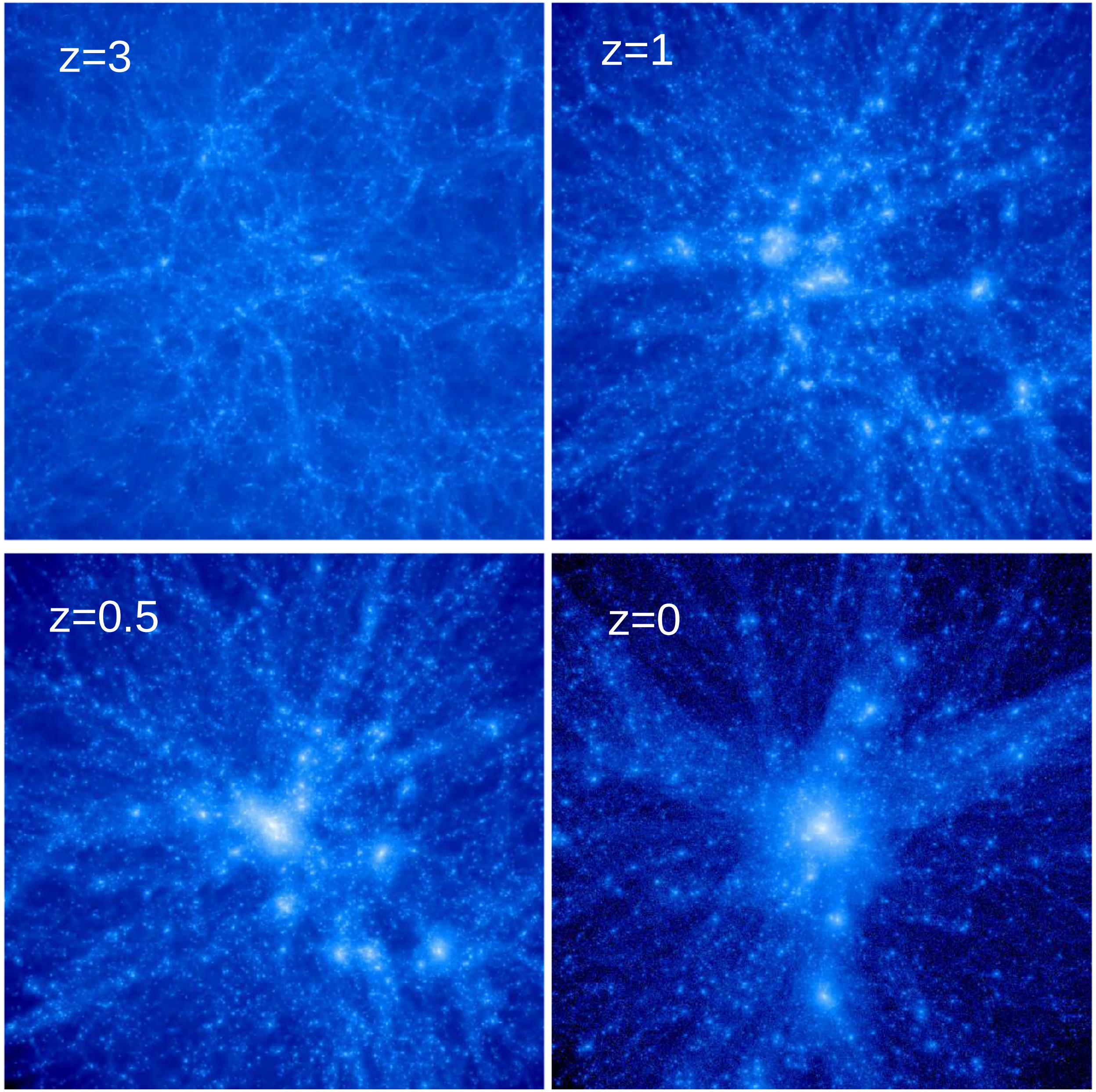
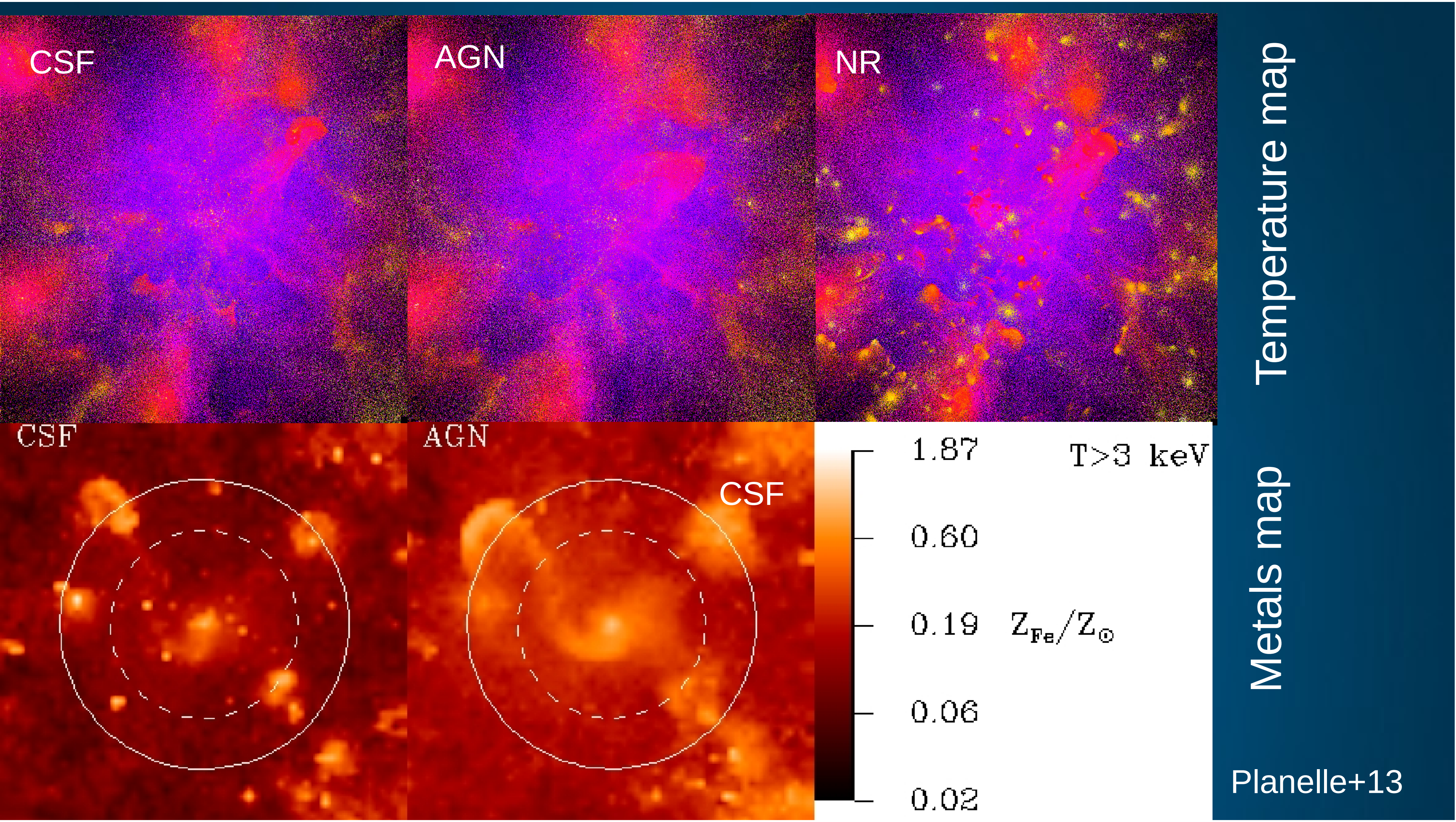


Image credit: Kravtsov & Borgani (2012)


CSF
AGN
NR
Temperature map
CSF
AGN
CSF
1.87
0.60
0.19
0.06
0.02
T>3 keV
$Z_{Fe}/Z_{\odot}$
Metals map
Planelle+13

Clusters are at the crossroad of astrophysics and cosmology

In essence:

a) clusters interesting in their own (cluster gastrophysics)

Clusters are at the crossroad of astrophysics and cosmology

Tension caused by new physics, lack of knowledge about cluster physics or systematics?

b) Need to be understood for cluster cosmology, in particular their variance.

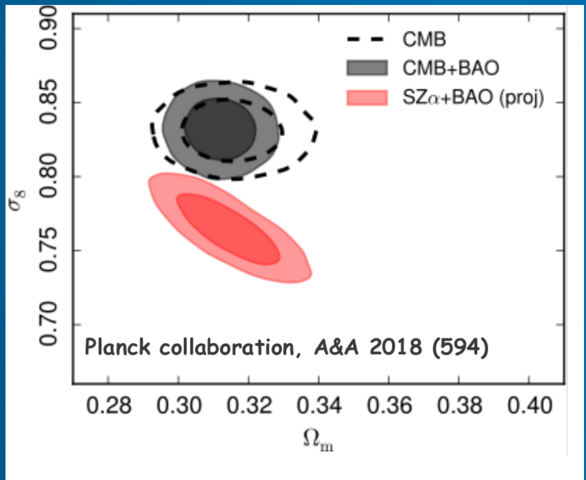
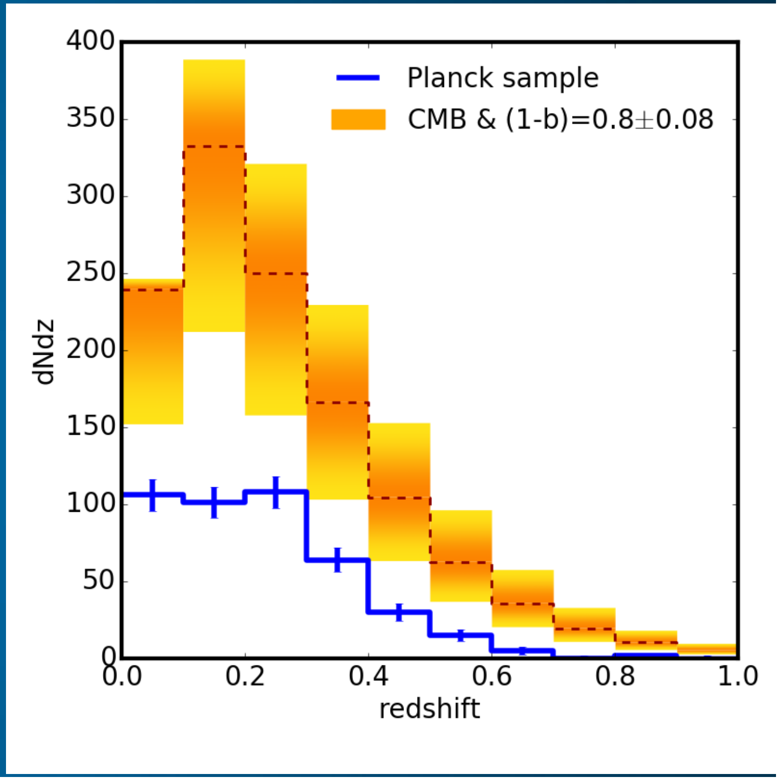
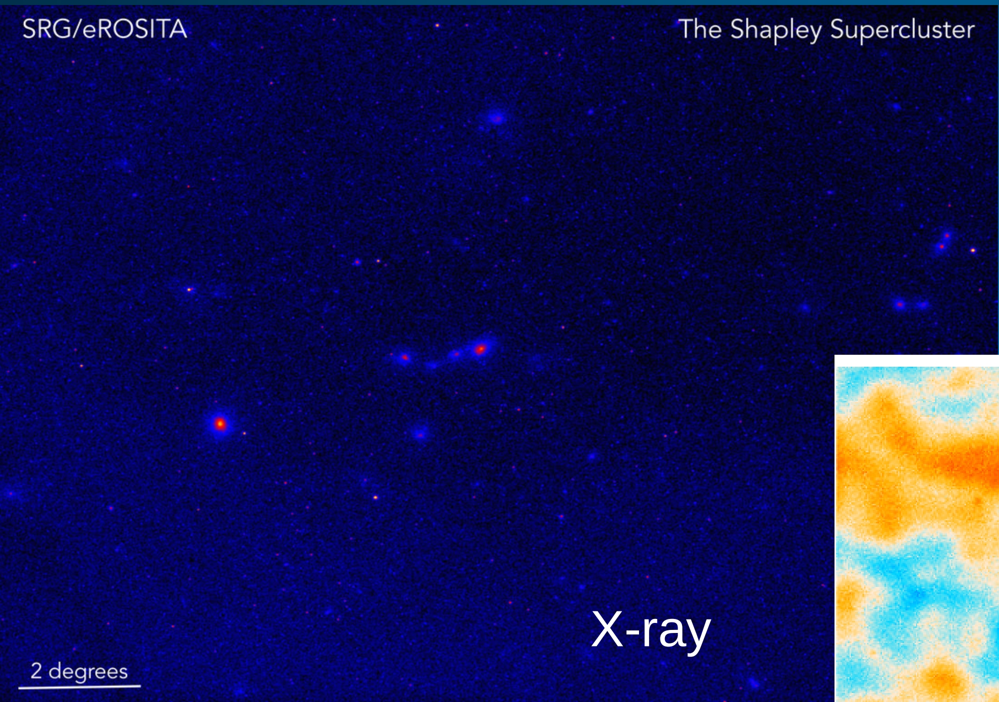
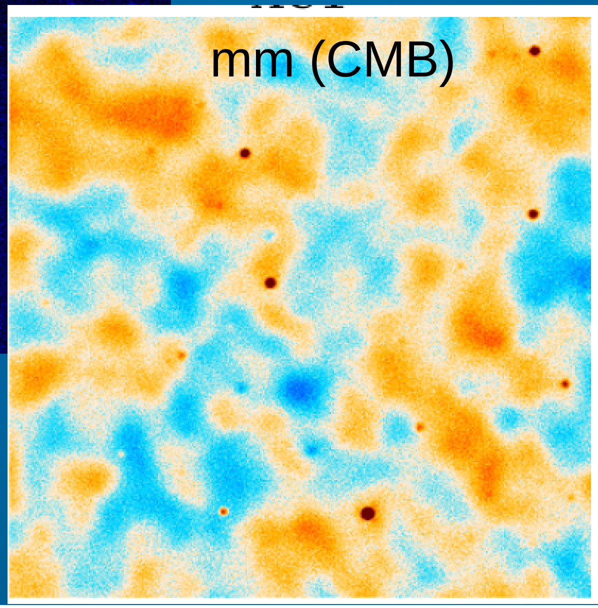


Figure from Salvati et al. 2018, see also Planck Coll, XX 2014



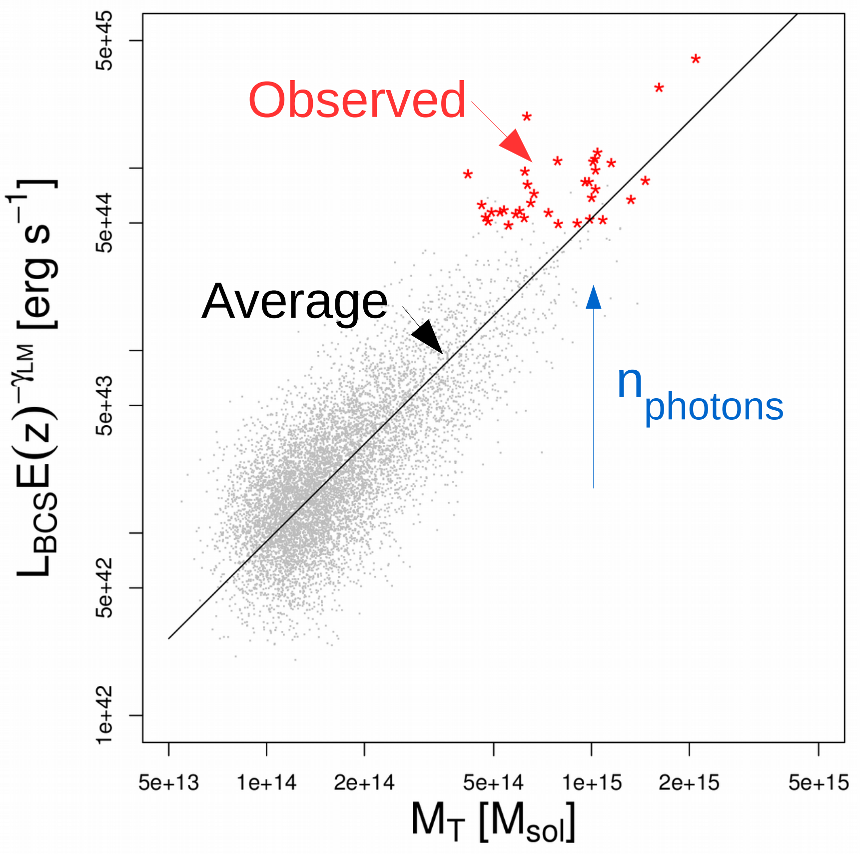
Detected by ICM (in X-ray, SZ), by galaxies (in optical/NIR) or by total mass (shear)





Why our view of clusters might be biased by the way we detect/select them?

… because the dim part of the population is more easily missed



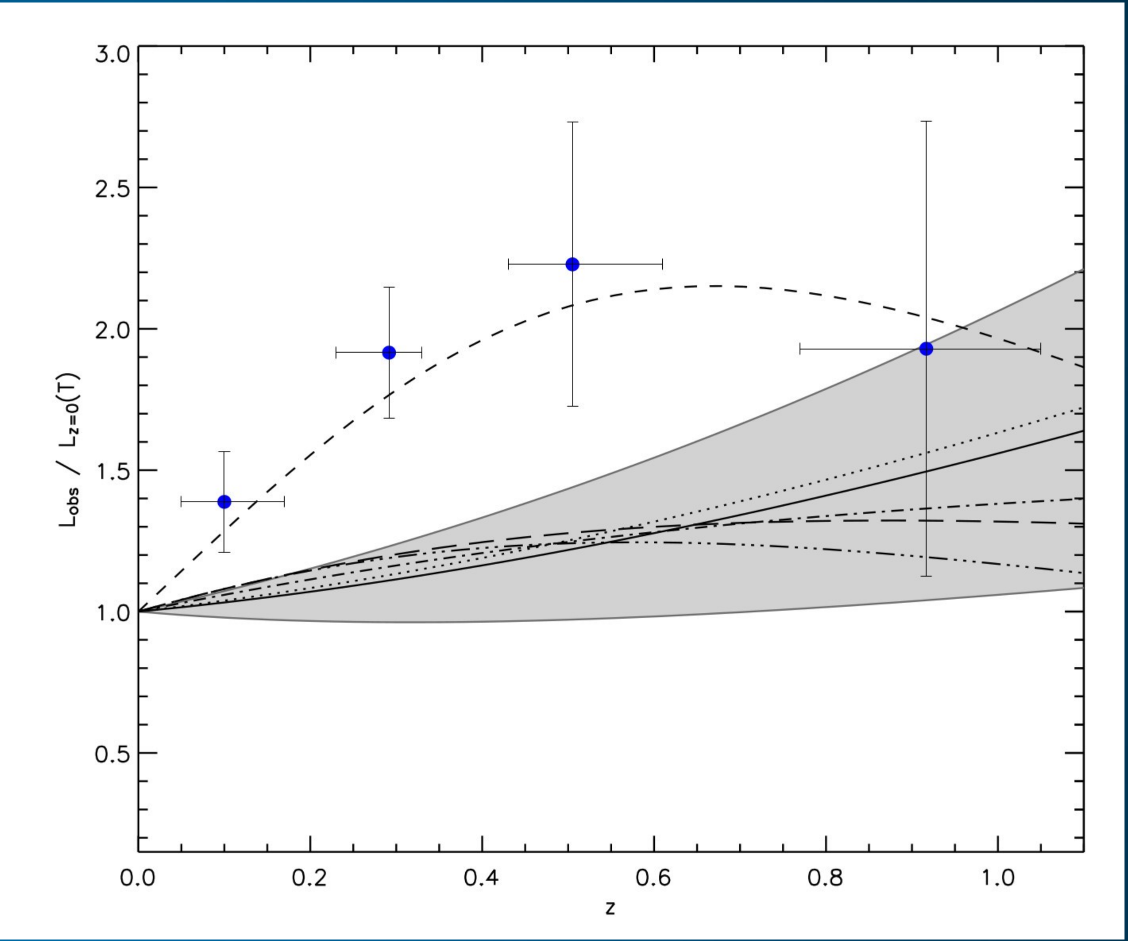
Location of average depends on assumptions (size and spread) about the missed population (the vertical scatter, Vikhlinin et al 2009, SA+11, SA & Moretti 11, etc).

All clusters are brighter-than-average in L_X-complete samples (and even more so in incomplete samples)

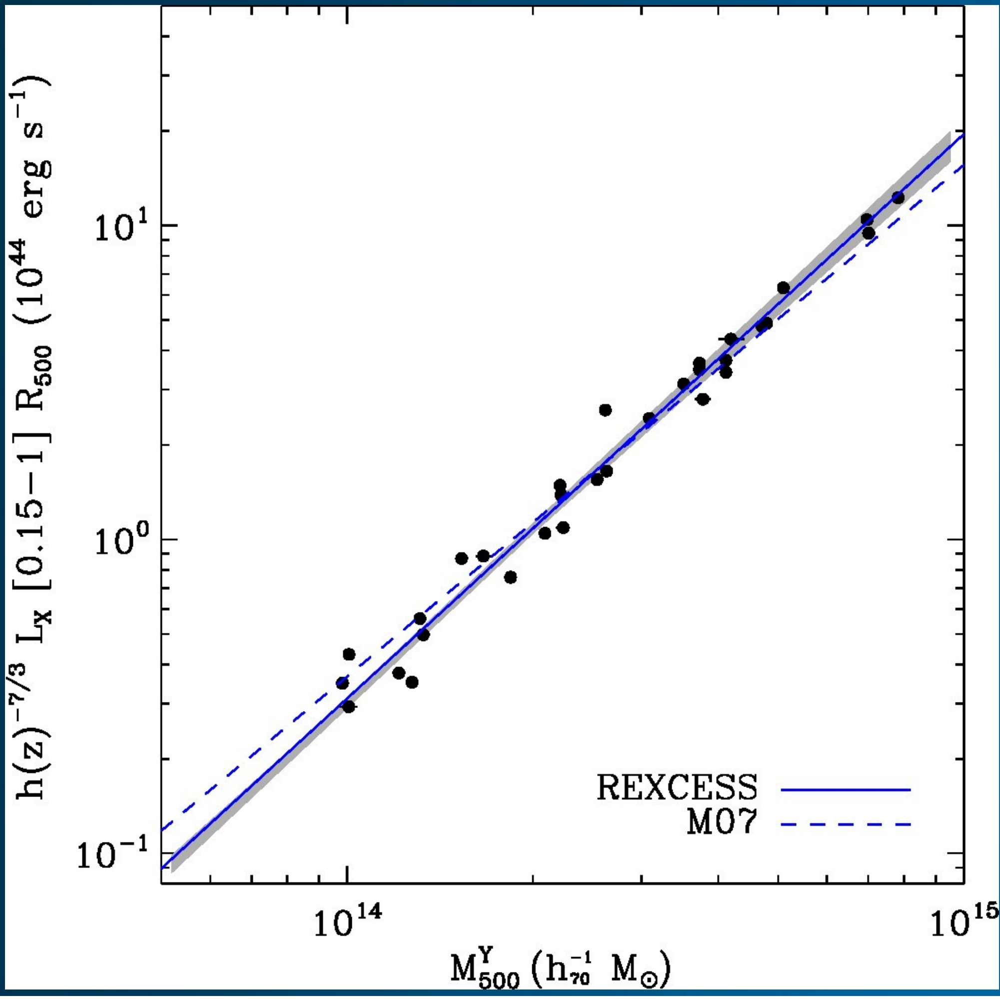
Figure from Giles et al. 2017, see also Pacaud et al. 2007, and many SA papers.

Already in 2007 ...

Pacaud, … SA, et al. (2007) first noted that X-ray selection important, later followed by many. Best fit passes below the points, i.e. the missed population is large.



Are X-ray selected clusters minimally biased ?



Pratt et al. (2009), REXCESS (R=Representative) and many later works, X-ray selection less important, best fit passes in the middle of the points, $\sigma(L_{X,ce}|M)$=0.07 dex (MB corrected).

This sample is used for building the Universal Pressure Profile, used to detect or measure mass in SZ surveys.

Is our view of clusters biased by the way we detect/select them?

i.e. how large is the scatter in the observable at a given mass?

Needed a selection independent of the ICM ...

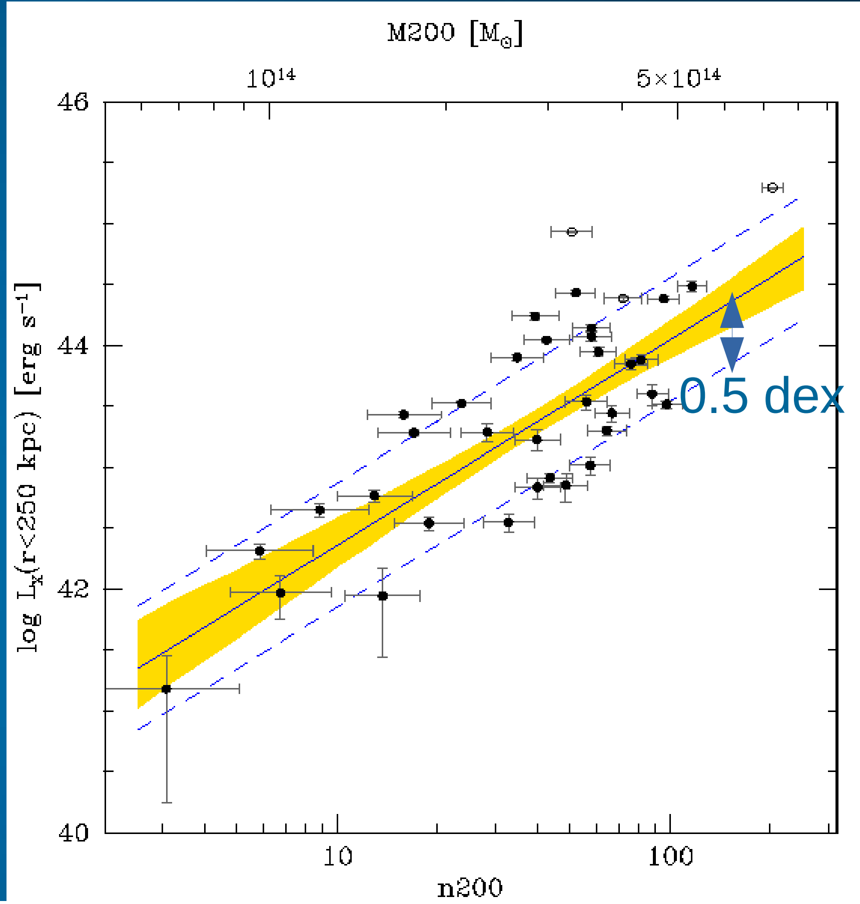
… the correction for missed population is neant because p(in the sampe)=1 independently of Lx.

Larger scatter (0.5 dex) than ICM-selected samples (SA & Moretti 2011, see also Planck collaboration 2011, Person et al. 2017, Ge et al. 2019; Rossetti+ Lovisari+, ...).

1) Most literature works select clusters using the ICM, which requires to make assumption on the unseen population, which leads to different stated amplitudes of the scatter.

2) All these works us a a mass proxy (richness, optical/NIR luminosity, SZ strength, etc.) not a direct mass estimate.

Figure from SA & Moretti (2011), 1.4 Ms XRT



Going for mass & p(in the sample) independent of Lx|M: XUCS, the X-ray Unbiased Sample

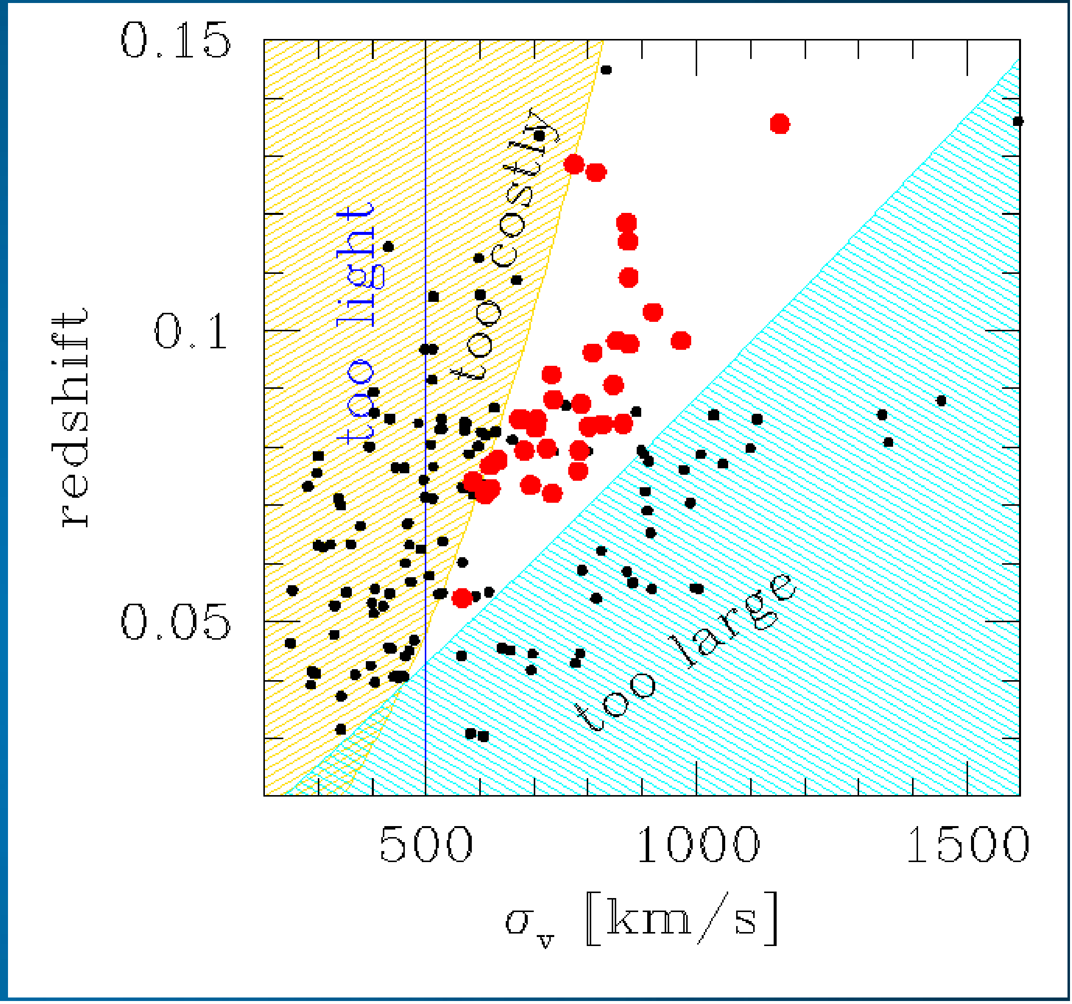
34 clusters, 0.05<z<0.135, at least 50 spectroscopic members within 1 Mpc in SDSS

No ICM selection at a given M.

13.5<lgM<14.7, mostly at

14<lgM<14.5 like REXCESS (except for the non-X-ray selection).

All followed up for ~10-30 ks, mostly with XRT, 420 (median) net photons [0.5-2] keV over a negligible background.



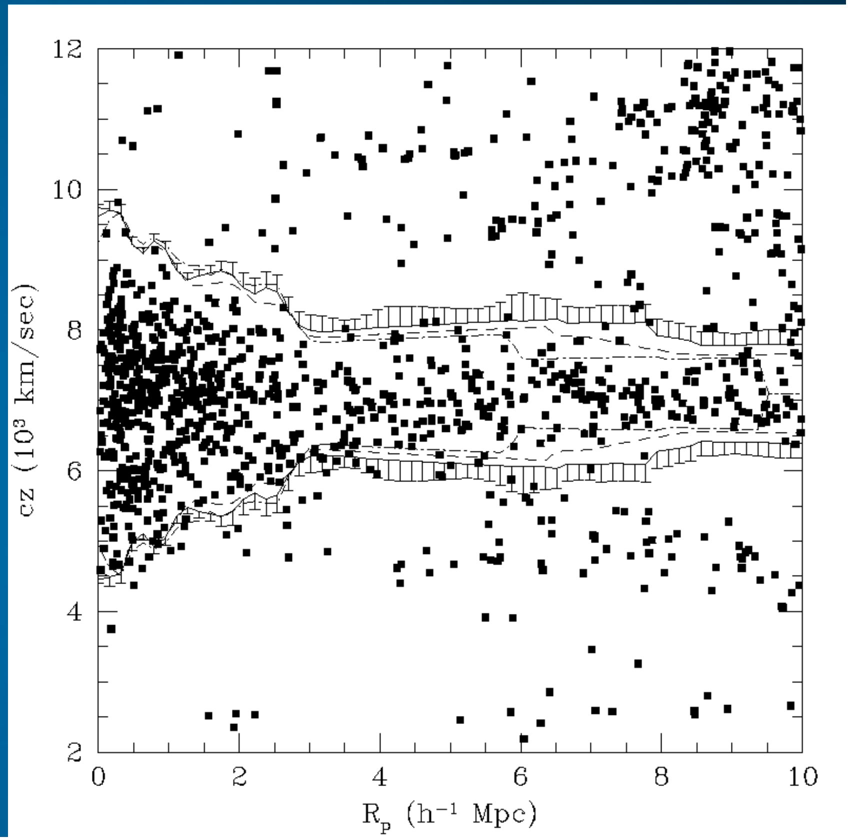
Second critical ingredient: Mass

Caustic masses (=escape velocity). Not requiring dynamical or hydrostatic (or whatever) equilibrium.

In XUCS, caustic + dynamical masses for all, hydrostatic masses for some (consistent).

116 member galaxies per cluster on average.

Figure from Rines+01



Swift XRT superiority for extended sources

Our preferred choice: XRT

A=eff. Area, F=focal ratio, B= detector background

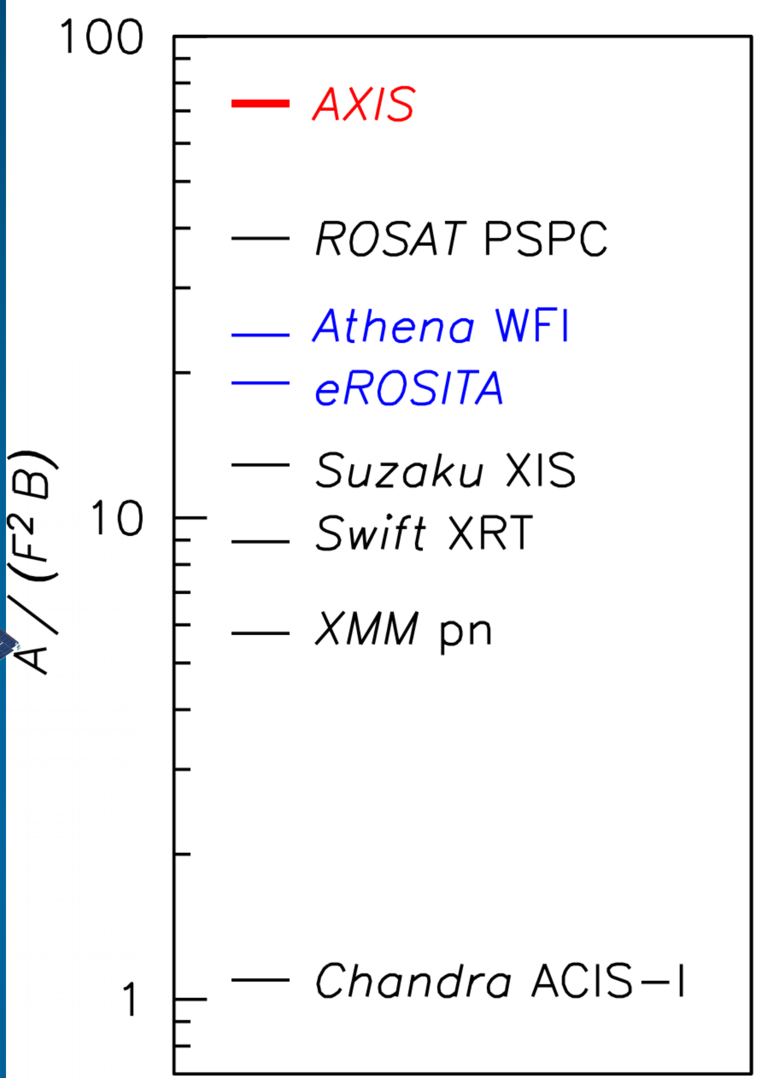
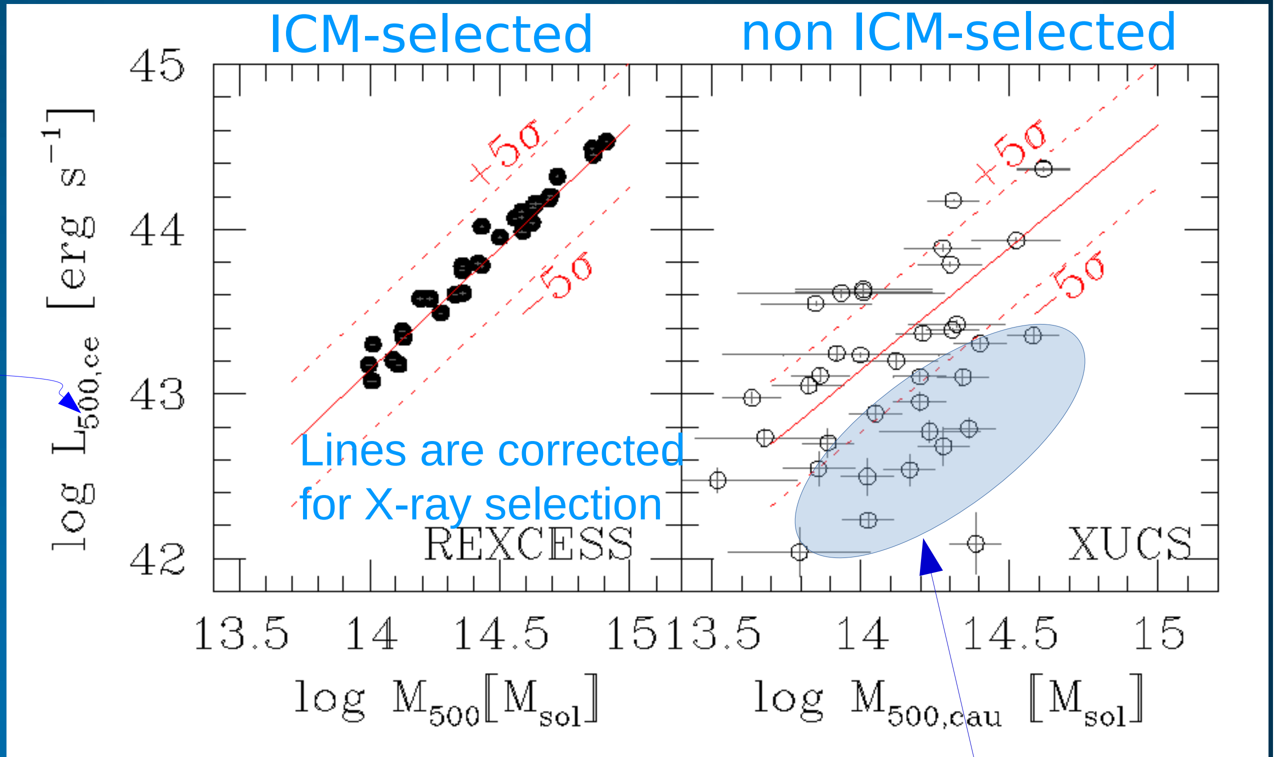


Figure from Mushotzsky+19, Walker+19 (Astro2020)

Recovering the missed (in X-ray) population

Core excised L_X → Scatter not due to CC

Scatter is 0.5 dex (as in SA+ & Moretti 11)

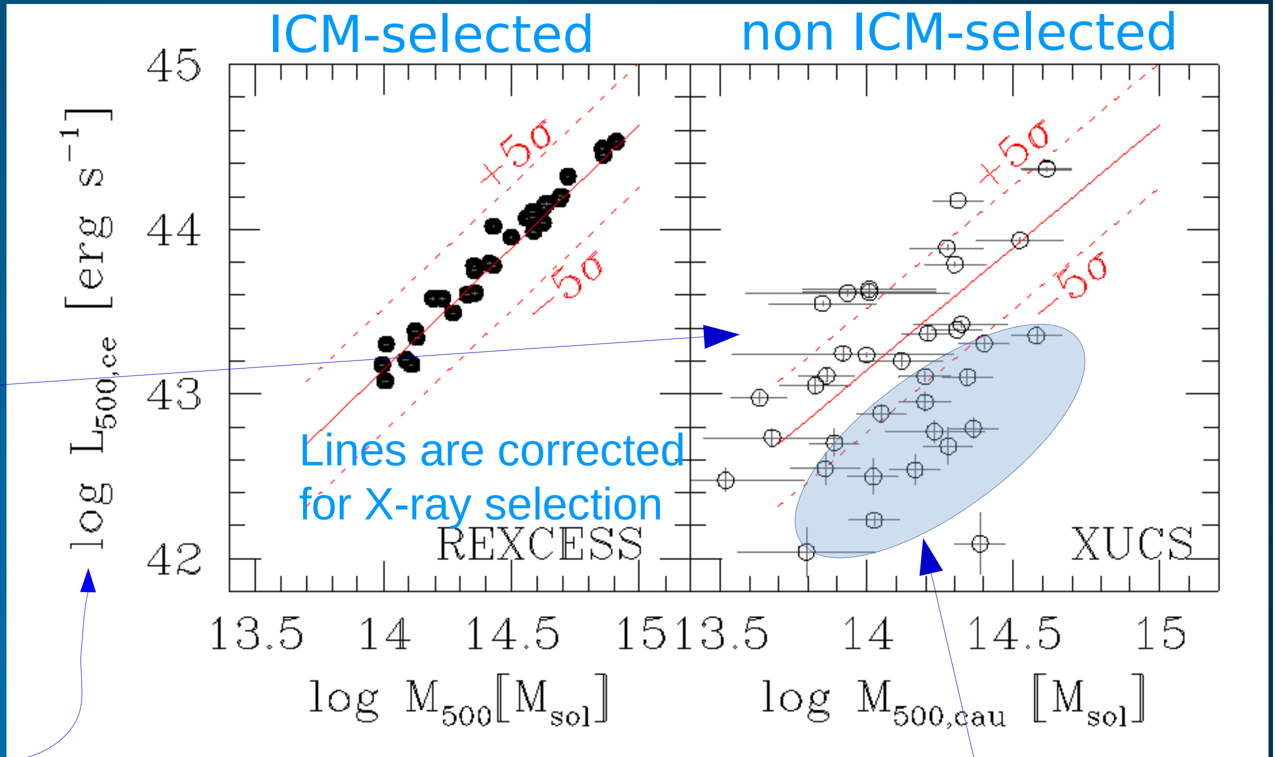


None should exist if X-ray samples were representative. Astrophysically interesting objects.

Figure adapted from A+16

Impact on cosmology with X-ray clusters

7 times larger scatter. It degrades constraints on σ_8 (Lima & Hu 2005) by a factor 50.



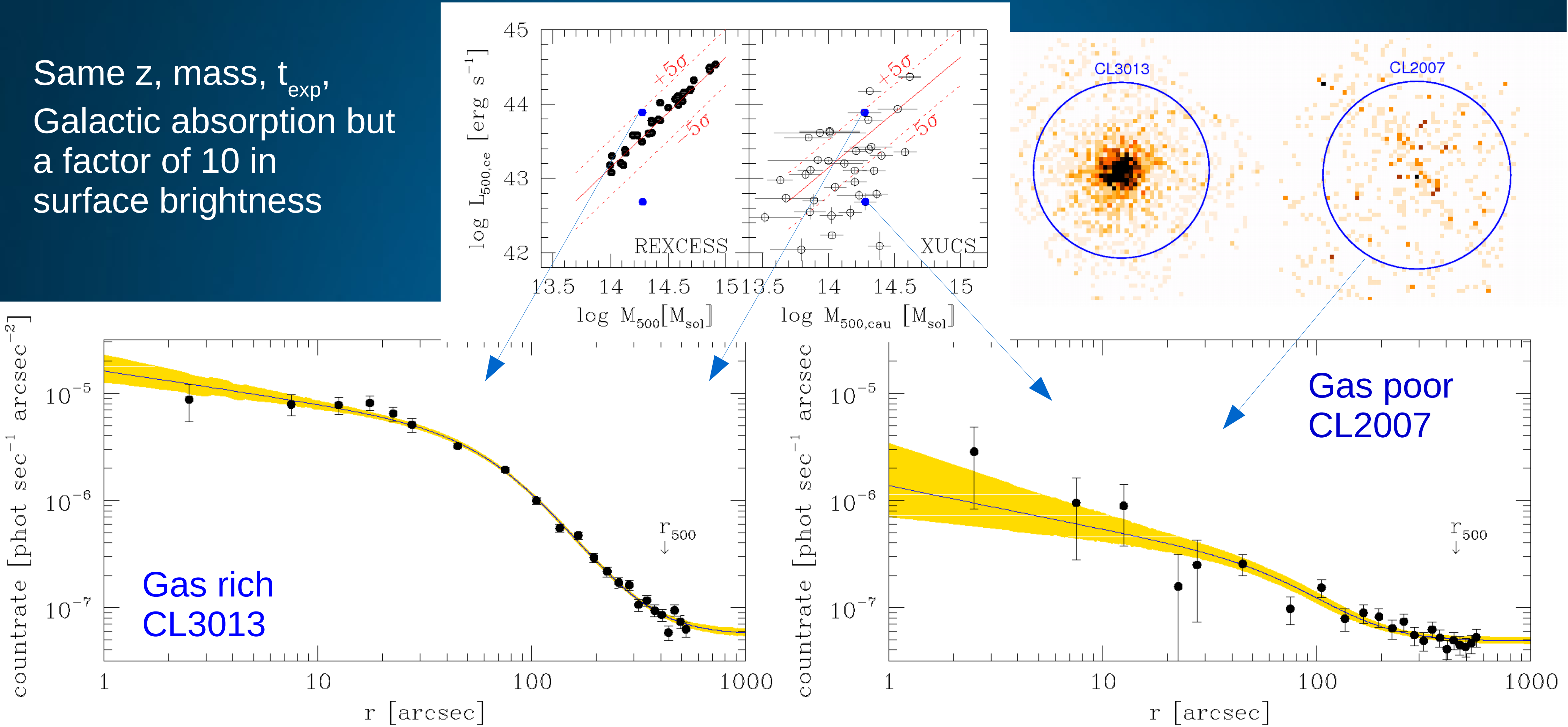
Core excised L_X

The same as used by eROSITA as mass proxy

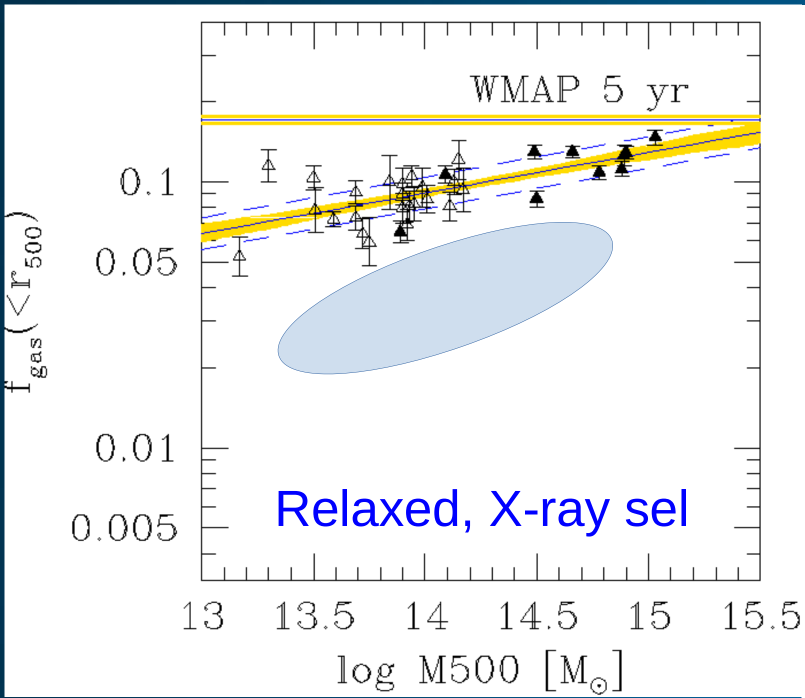
Poor control on selection function, danger for cosmology

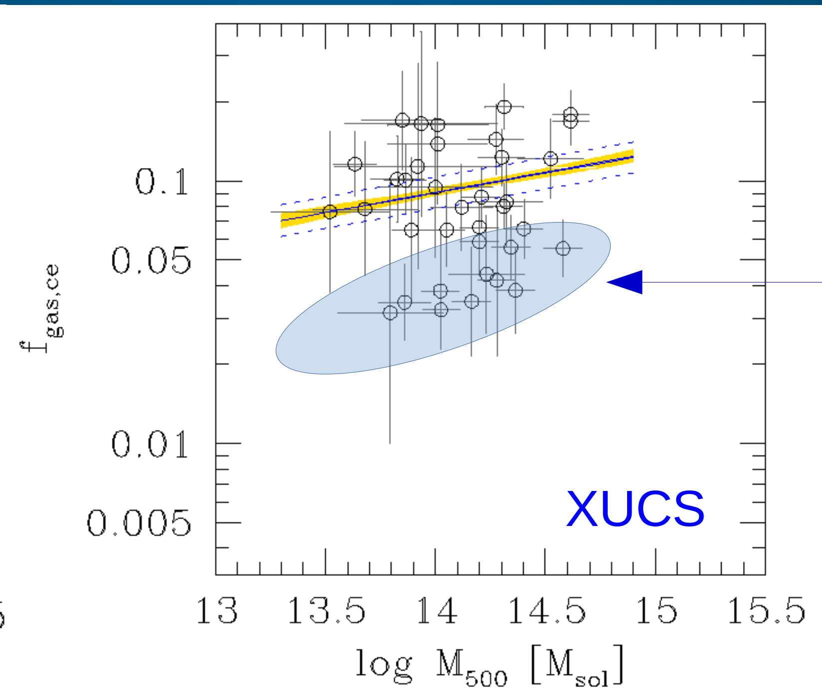
All L_X faint|M are of low surface brightness

Same z, mass, t_{exp}, Galactic absorption but a factor of 10 in surface brightness



Gas-poor clusters



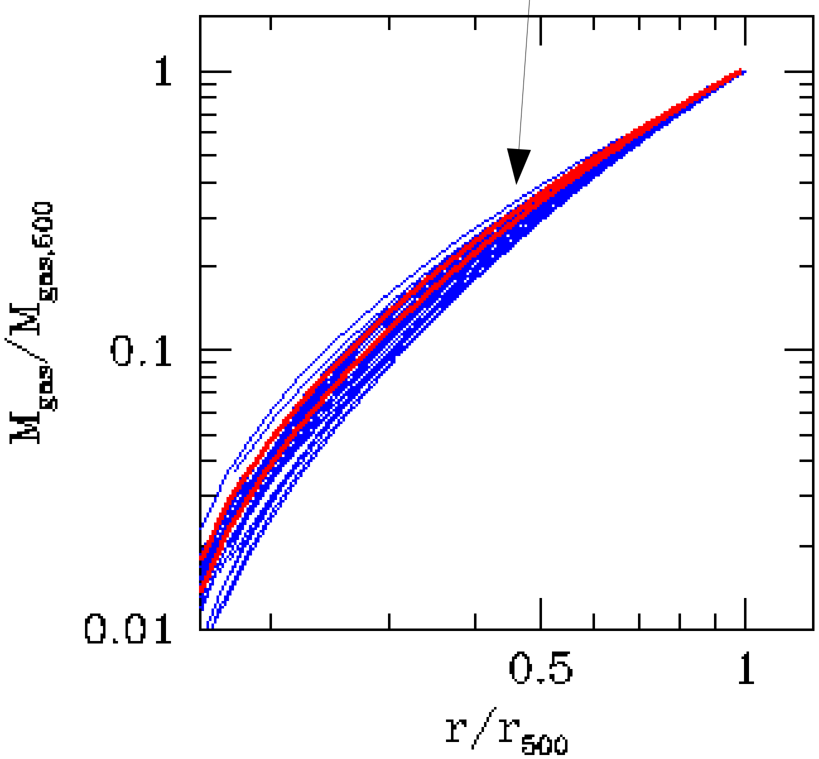


Gas poor, Under-represented in X-ray samples

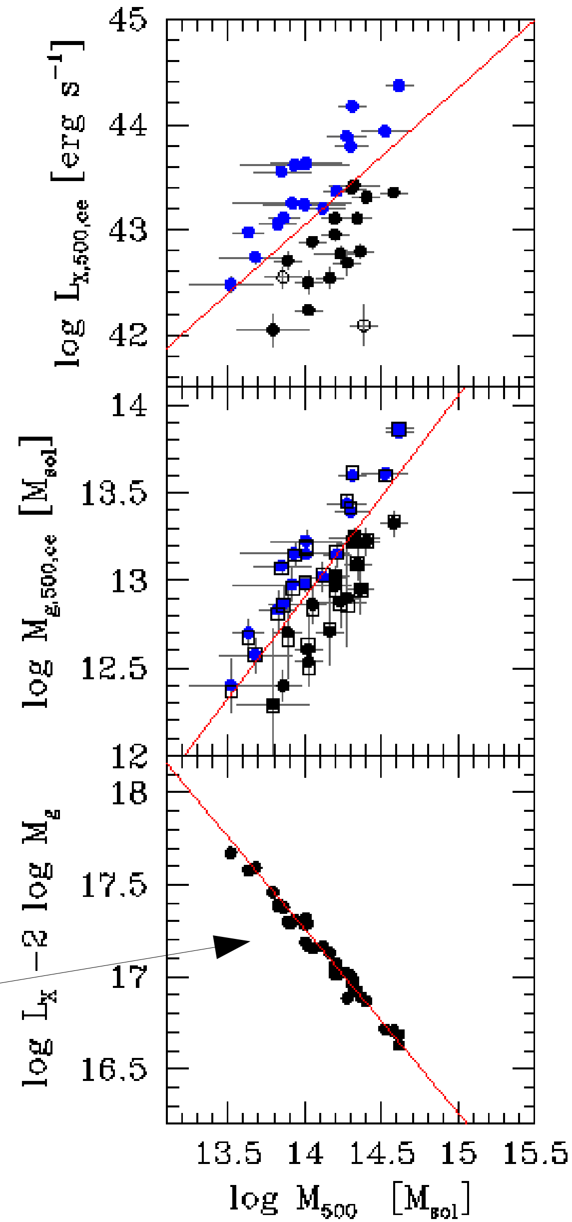
Figures adapted from A10 and A+16

Most of the variety is associated to f_{gas}

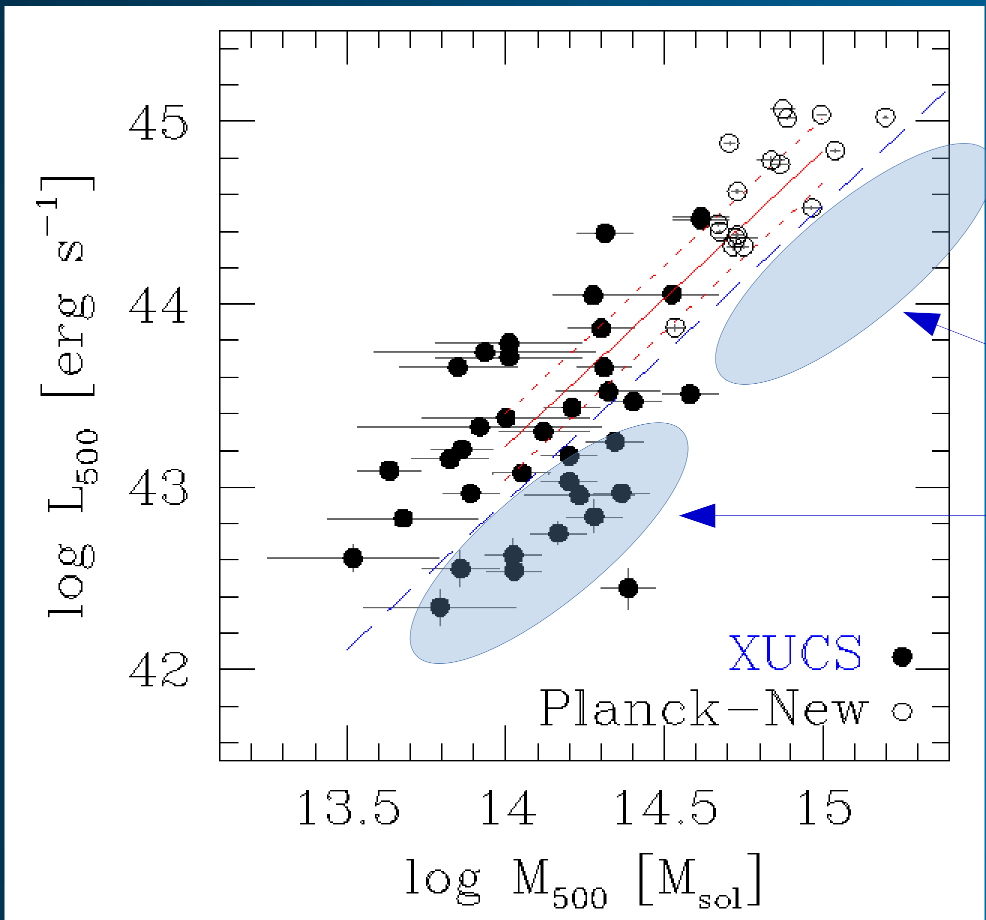
Gas mass profiles become identical after accounting for f_{gas}



and L_X-M becomes almost scatter-less once accounted for gas fraction



Larger variety than seen by Planck



Empty in Planck!

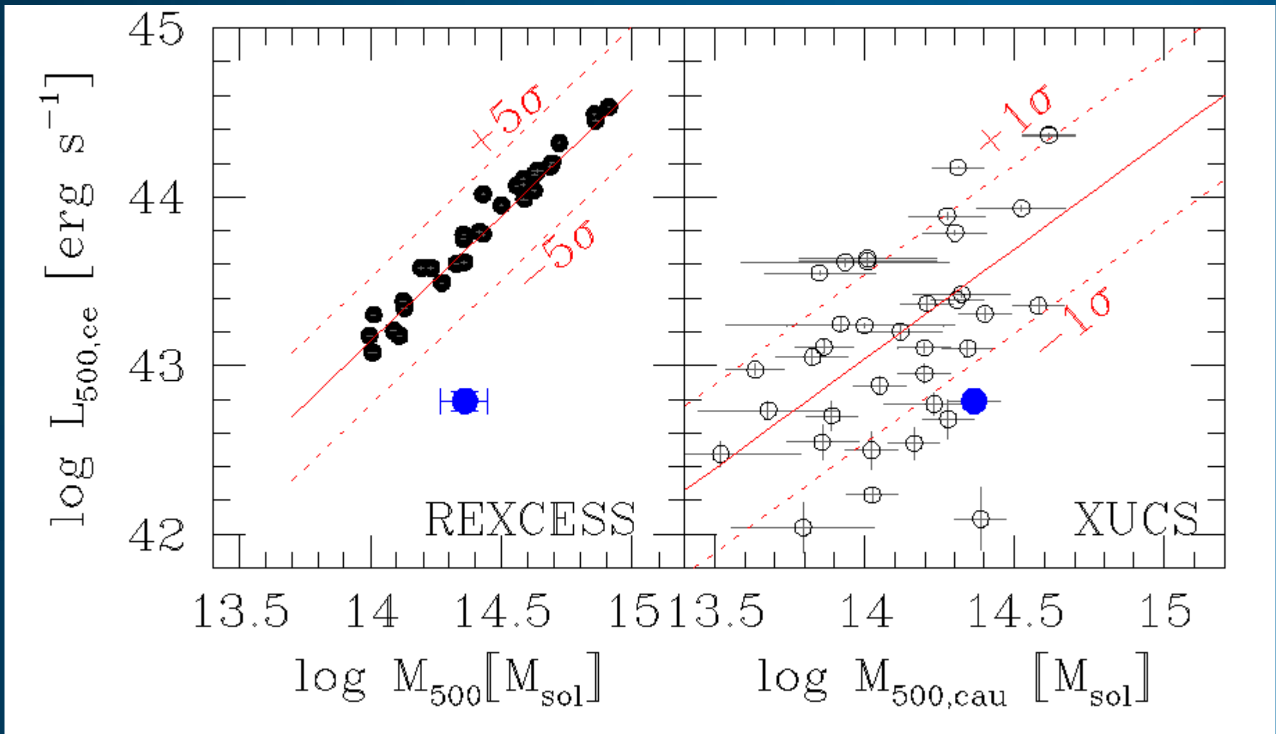
Gas poor

Planck sees a reduced variety because select clusters using ICM.

Y_{SZ} selection could be possibly biased!

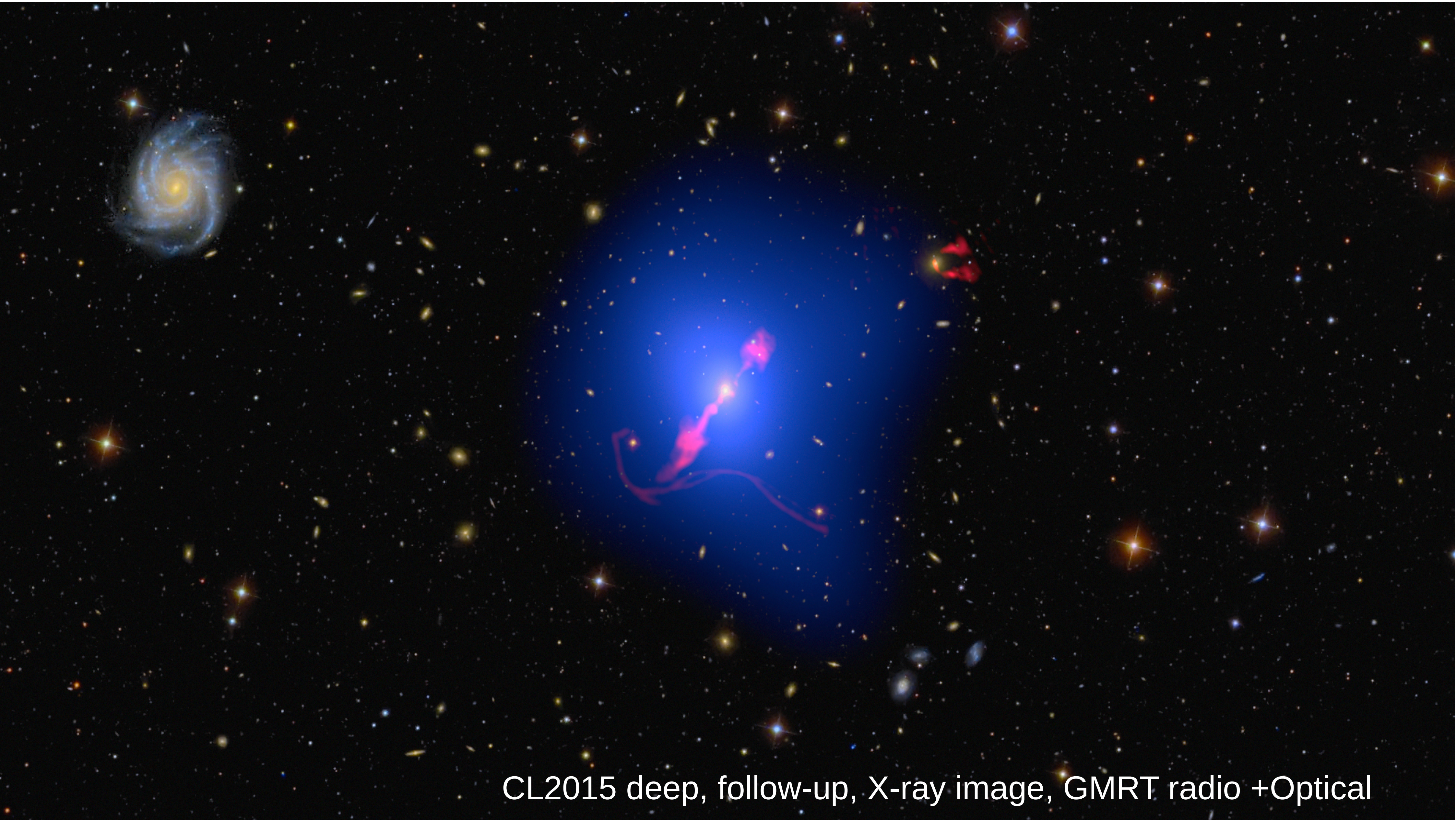
Figure adapted from A+16

First X-ray deep follow-up: CL2015 selection



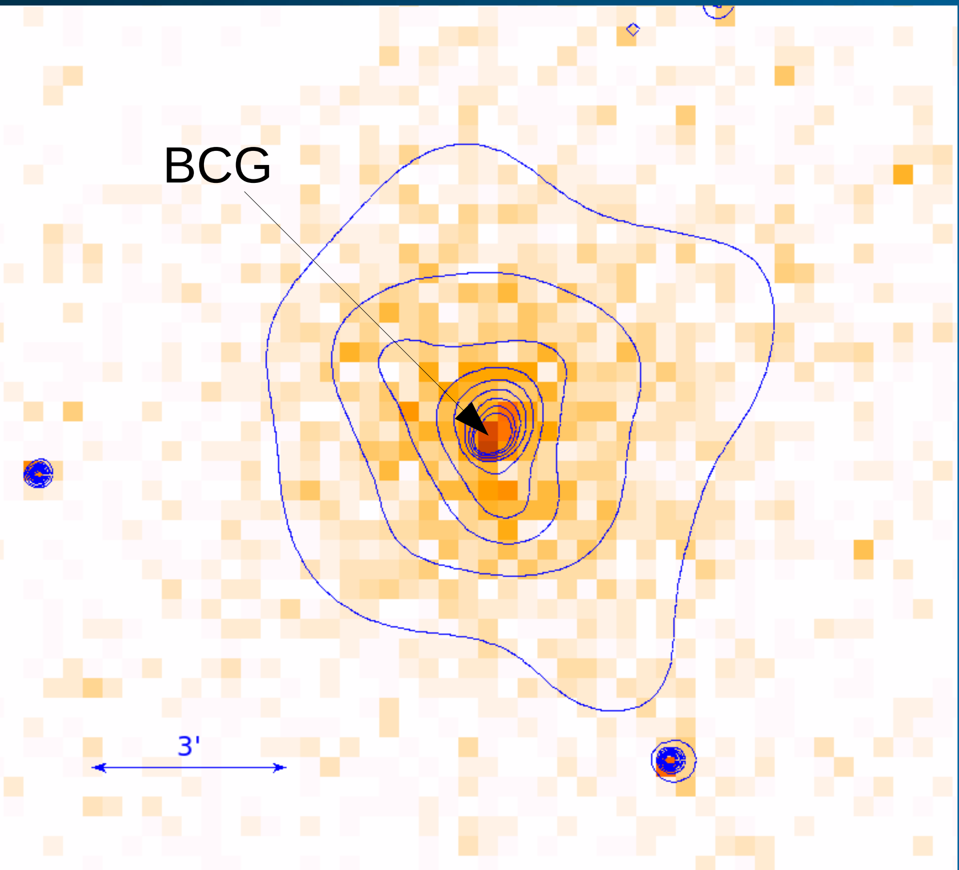
>10σ outlier for REXCESS, but only -1.5σ in XUCS

Same L_X from Einstein. For other clusters in the sample consistent Chandra, XMM, and Swift L_X

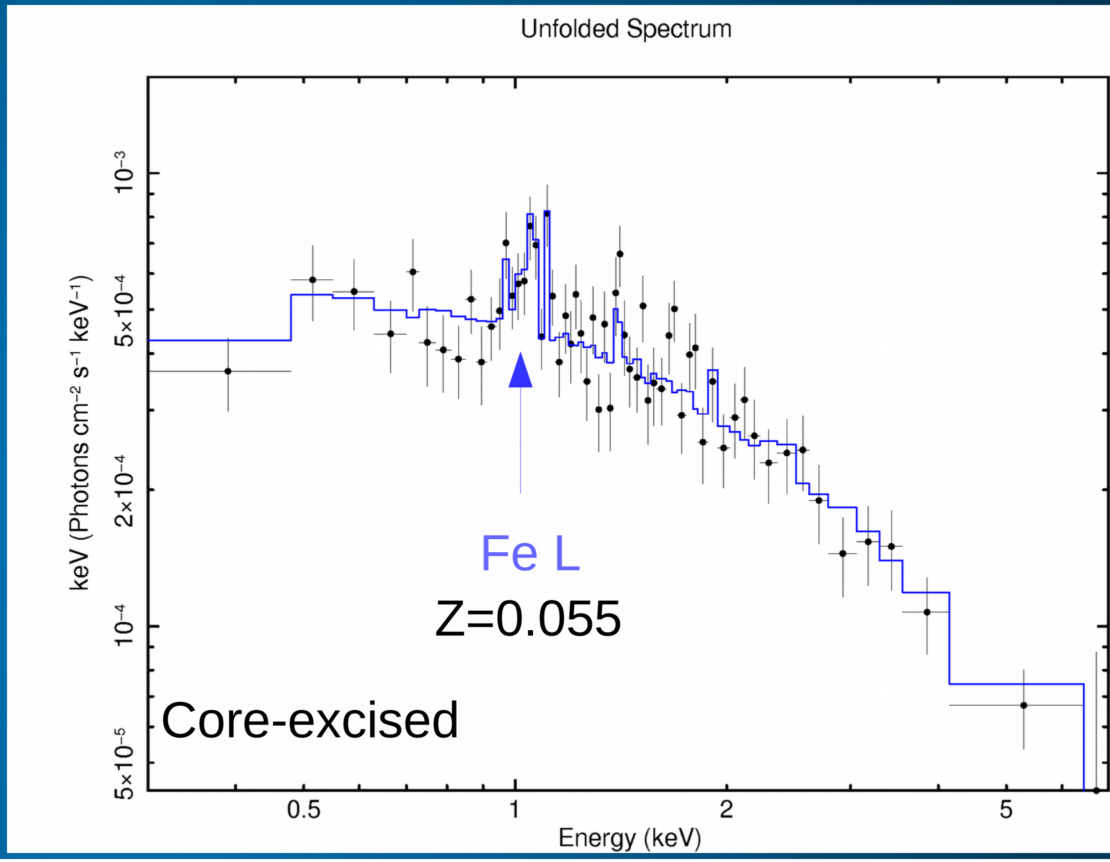

CL2015 deep, follow-up, X-ray image, GMRT radio +Optical

5000+ photons on a negligible bkg

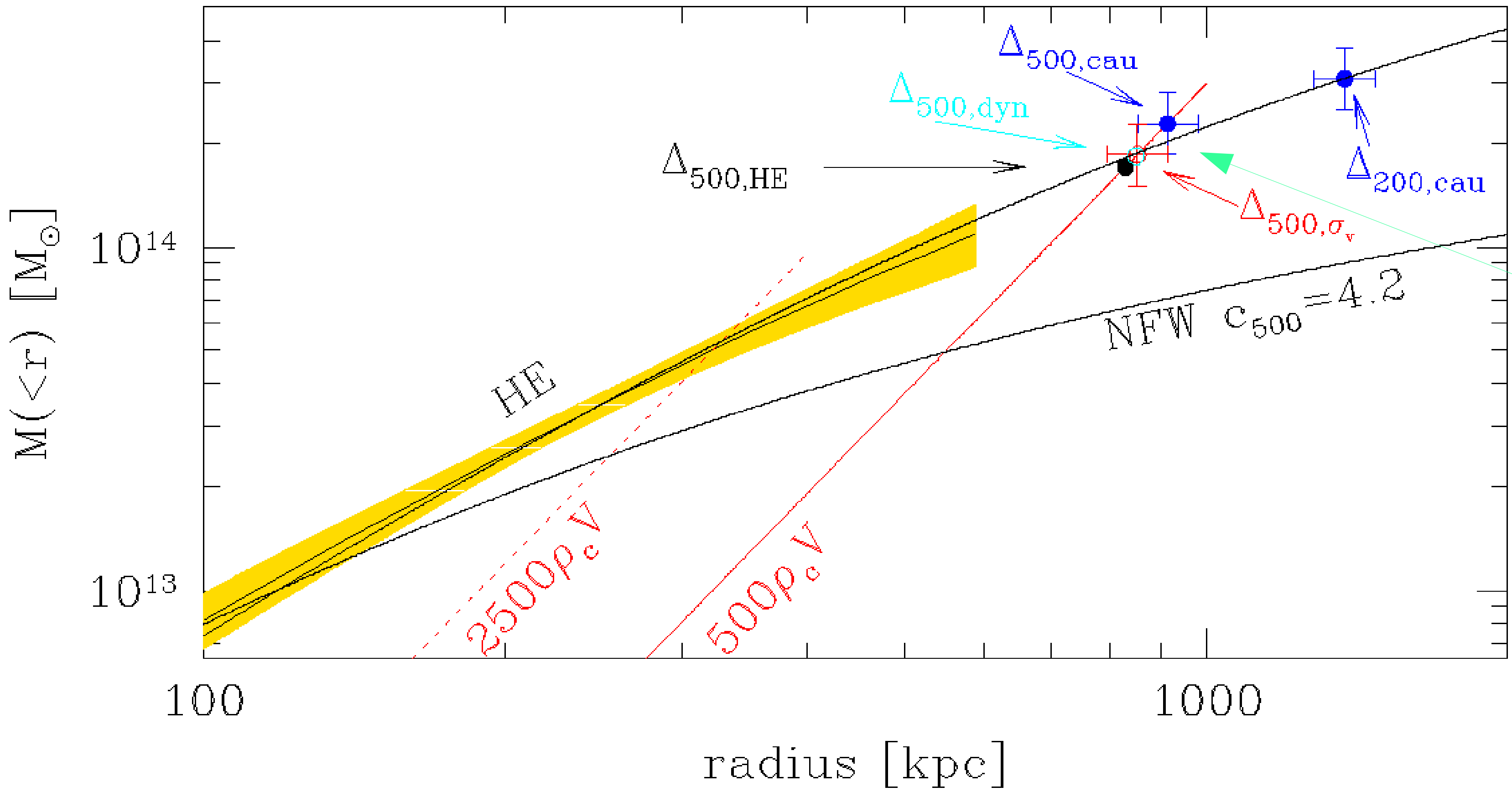
Identical X-ray and optical centers



Good T estimates, even outside the cluster center, in spite of the low surface brightness



X-ray faint because of the low concentration, with multiple paths to mass



Unusual (for X-ray selected) concentration c_{500}=1.5

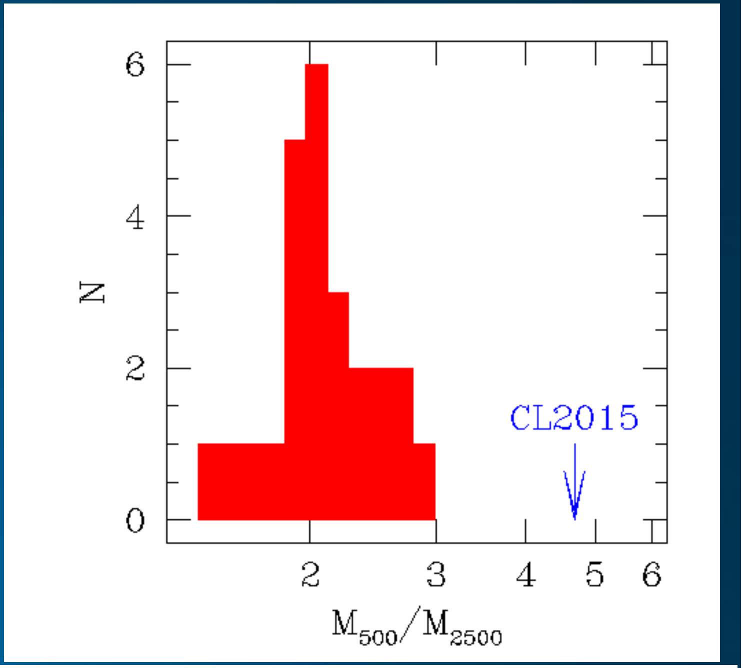
Consistent masses

from caustics, velocity dispersion, and HE

Mass is less concentrated than in X-ray selected clusters

High concentration of X-ray samples is a selection effect.

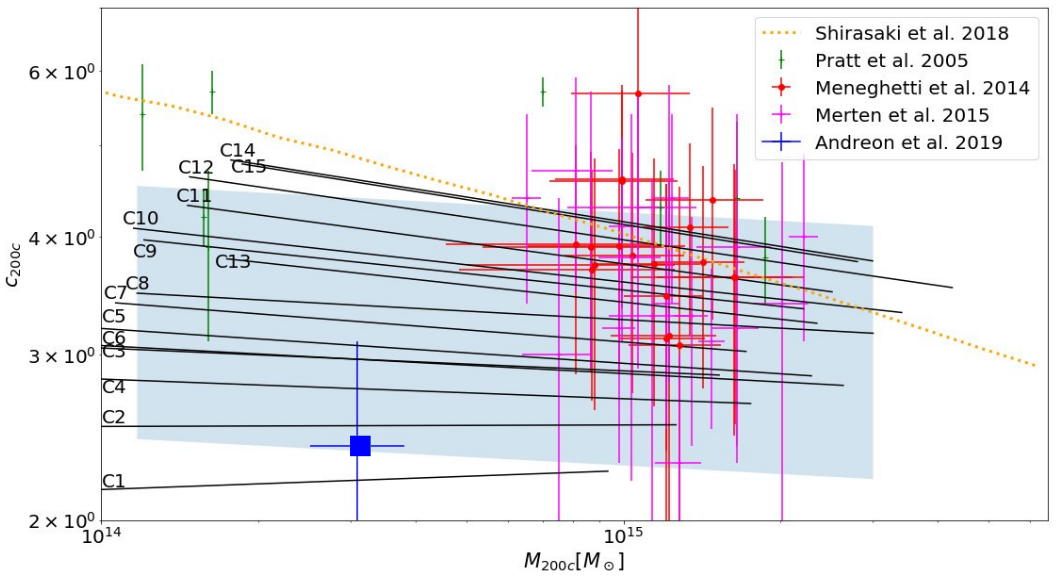
Comparison samples from Viklinin+06, Sun+09, Arnaud+05, Pointecouteau+05.



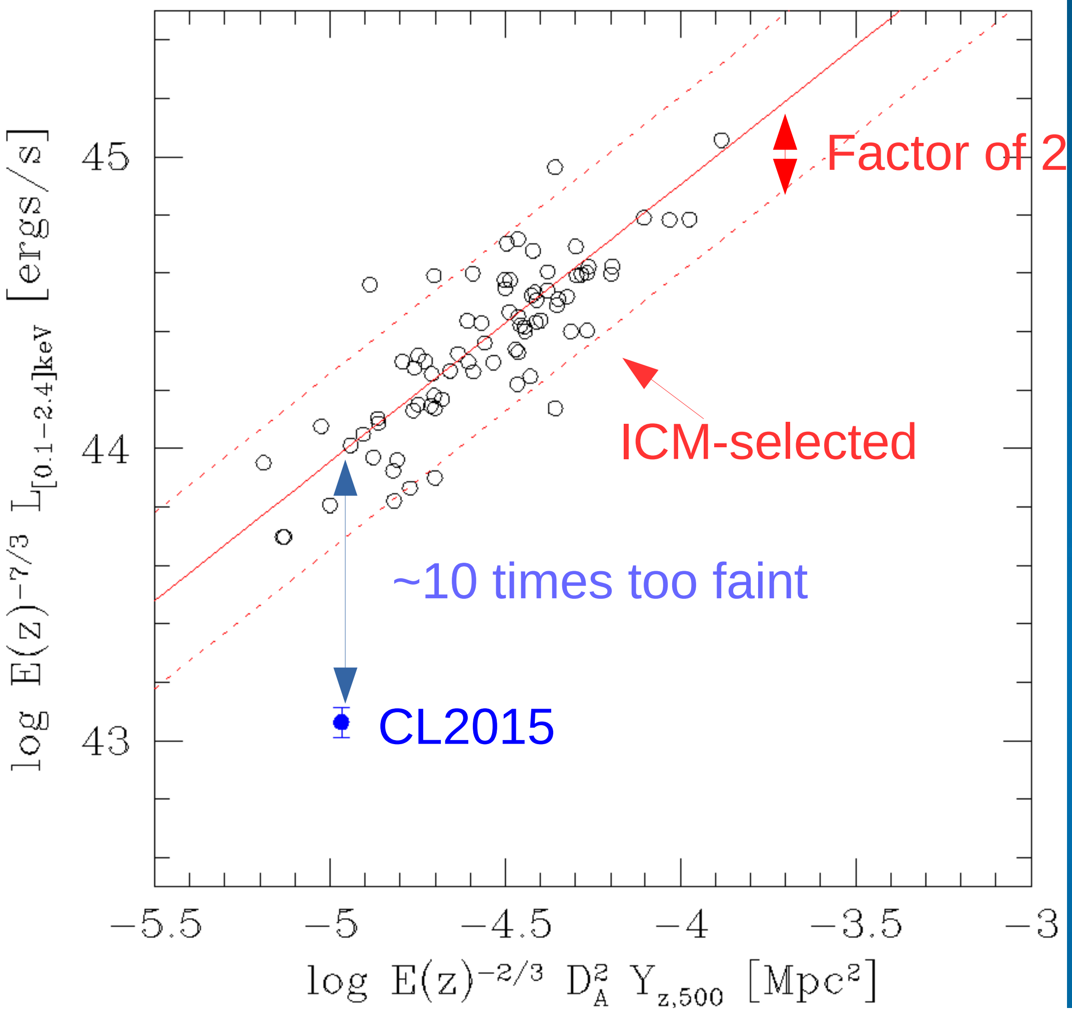
But not unusual in simulated samples (it is not a rare peculiar object).

Light blue: +/-1σ range from simulations including gas physics, star formation, AGN feedback, etc. (Ragagnin+20).

We are exploring if low-SB clusters have low gas fraction or low concentration in simulations and in a few real objects with adequate data.



Outlier in L_X-Y_{SZ} because of low concentration



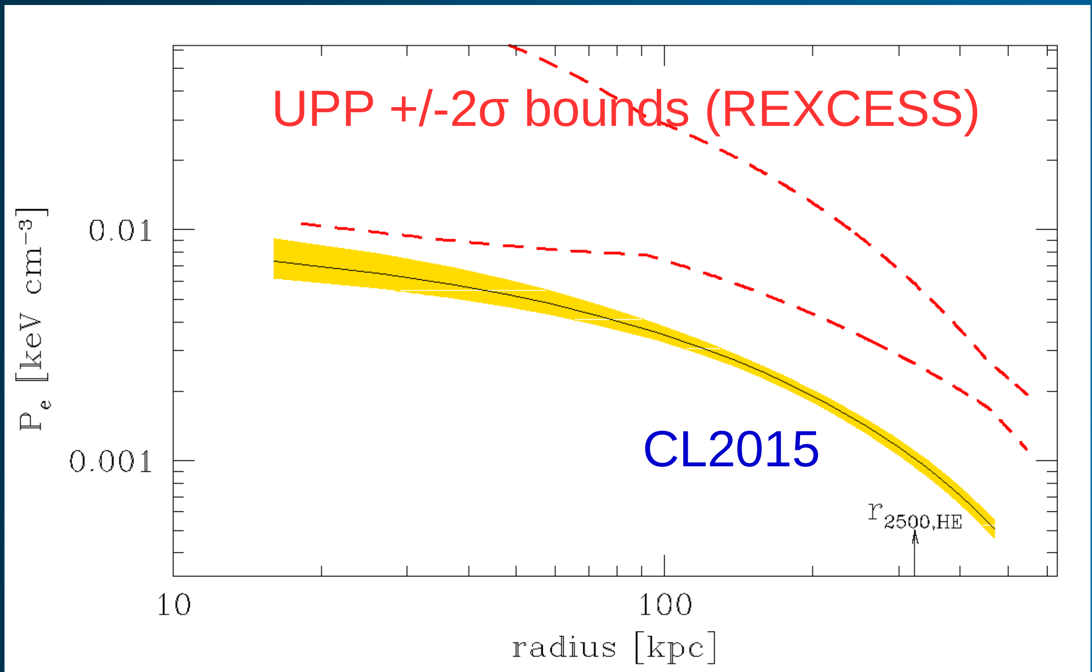
- Y_{SZ} dominated from large r (propto n_e)

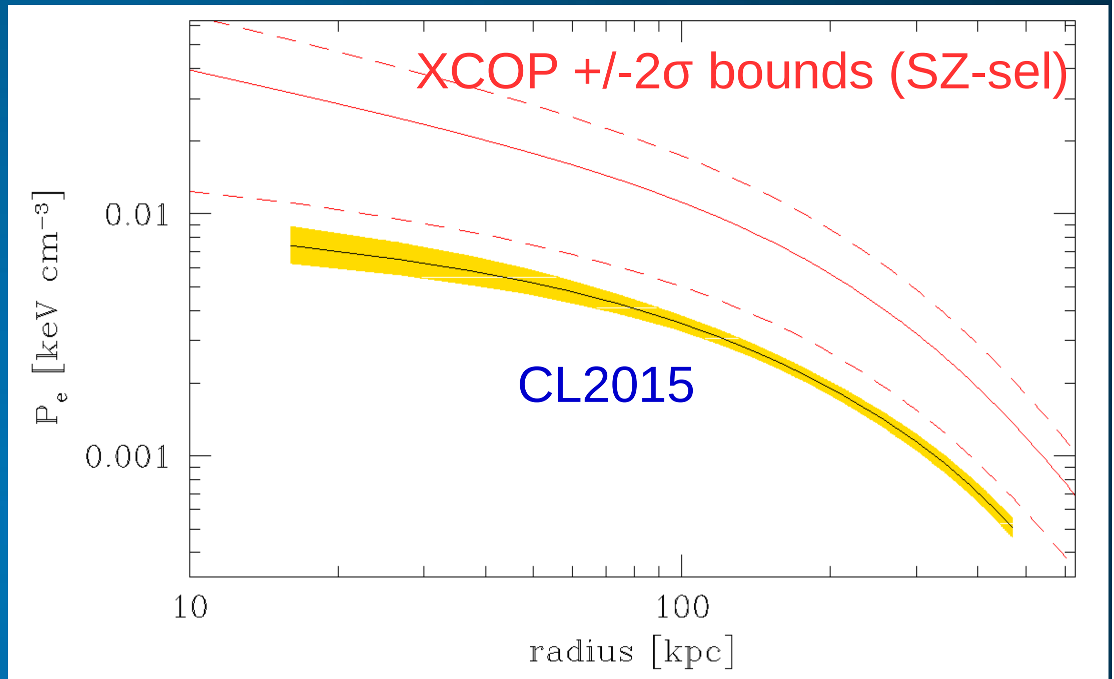
- L_X dominated from small r (propto n_e^2)

scatter in concentration → scatter in L_X-Y_{SZ}

CL2015 is the only gas-poor cluster detected by Planck (and at the very boundary, below detection threshold of MMF3!) Also Planck misses them!

Astrophysics implication: larger (than believed) variety in pressure profiles





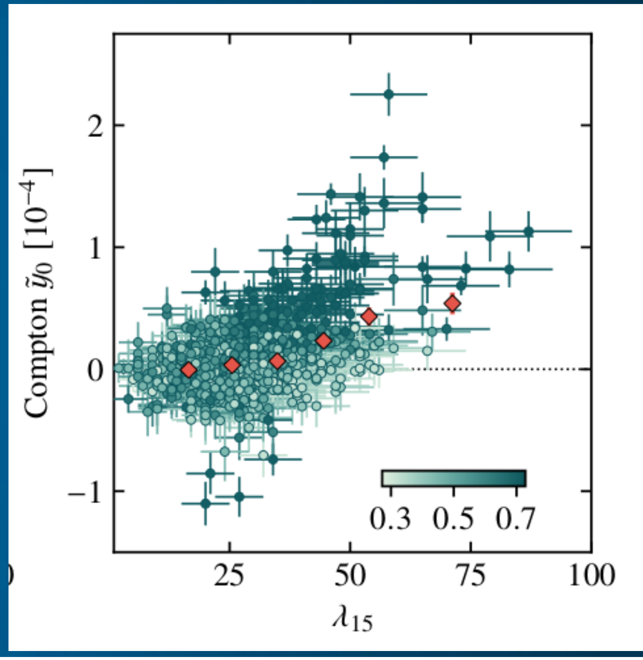
SZ selection don't capture the full variety of clusters (at a given M)

Implications for SZ-selected samples

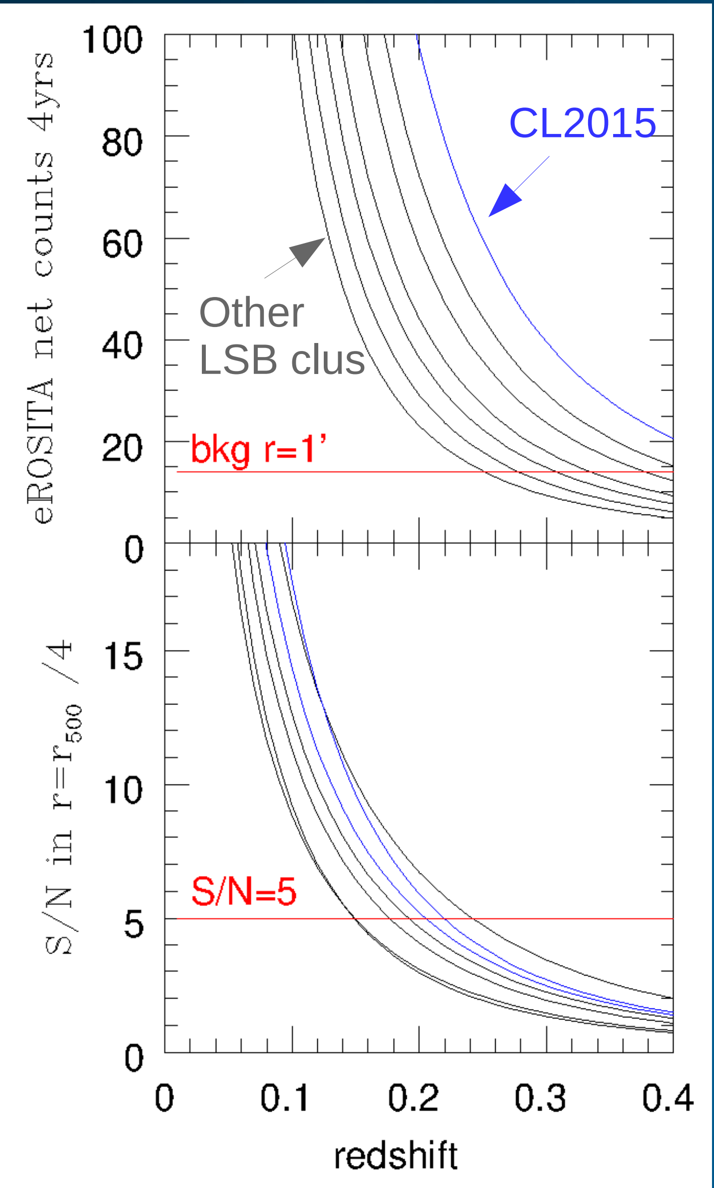
For some objects the wrong pressure profile is used to detect the cluster or to measure “mass” (integrated pressure, to be precise). Those will have wrong masses, or gone undetected, yet they exist.

A pressure-selected sample favors high-pressure clusters at fixed mass in spite of the strong advertising of the beauty of working with SZ-selected samples (XCOP, Planck* SPT* ACT*) stated by some individuals.

The existence of a larger variety than belived starts right now (Mai 2021) to be timidly recognized (Orlowski-Scherer et al. 2021). Here richness, not mass, is used, with the same limitation of my 2011 paper.

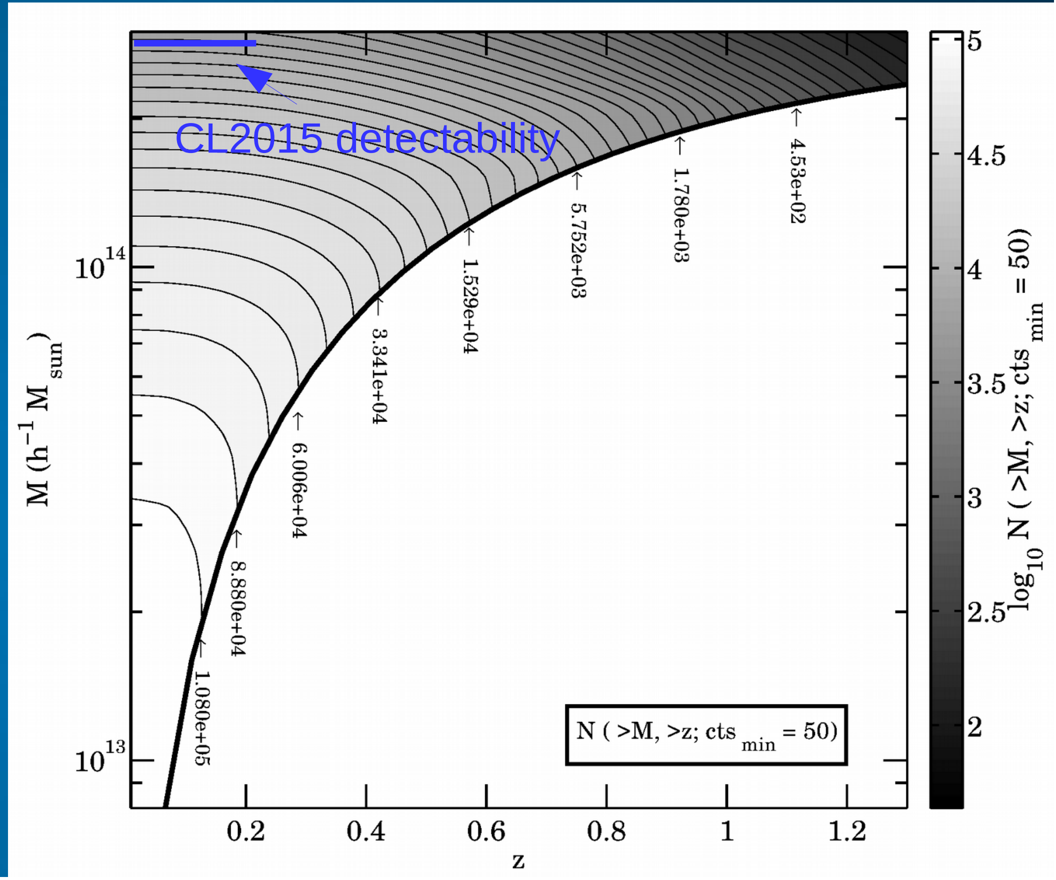


Detectable by eRosita to z~0.2 (because of LSB)



Rough (extrapolated) and preliminar estimate: 50% incompleteness at all/most masses (i.e. 1 missed cluster per detected one) at z>0.2.

To be assessed with more (deep) X-ray/SZ data of a non-ICM selected sample.



Summary:

1) Clusters are a more variegate population than someone believes: LSB clusters exist and start to be find by others,e.g. the extended groups by Xu et al. 2018. Some of our LSB clusters are re-discovered as X-ray faint in SPIDERS or CODEX. Weak-lensing selected clusters have <c500>~2.4, not ~4 as typical for X-ray selected samples. Bias of the ICM selection rarely emphasized in X-ray/SZ surveys, including eROSITA.

2) Selection by ICM (X-ray or SZ) tends now to be accounted for in scaling relations, without however to emphasize that the amplitude of the correction depends on assumptions on the unseen population (or assumptions on more complex quantities, such as covariance with …).

Good points:

→ A new population to characterize: why LSB? All low-concentration? Started observation follow-up and simulation analysis. Your help is welcome.

→ Accounting for the selection gives work for next generation of astronomers

Simplified message:

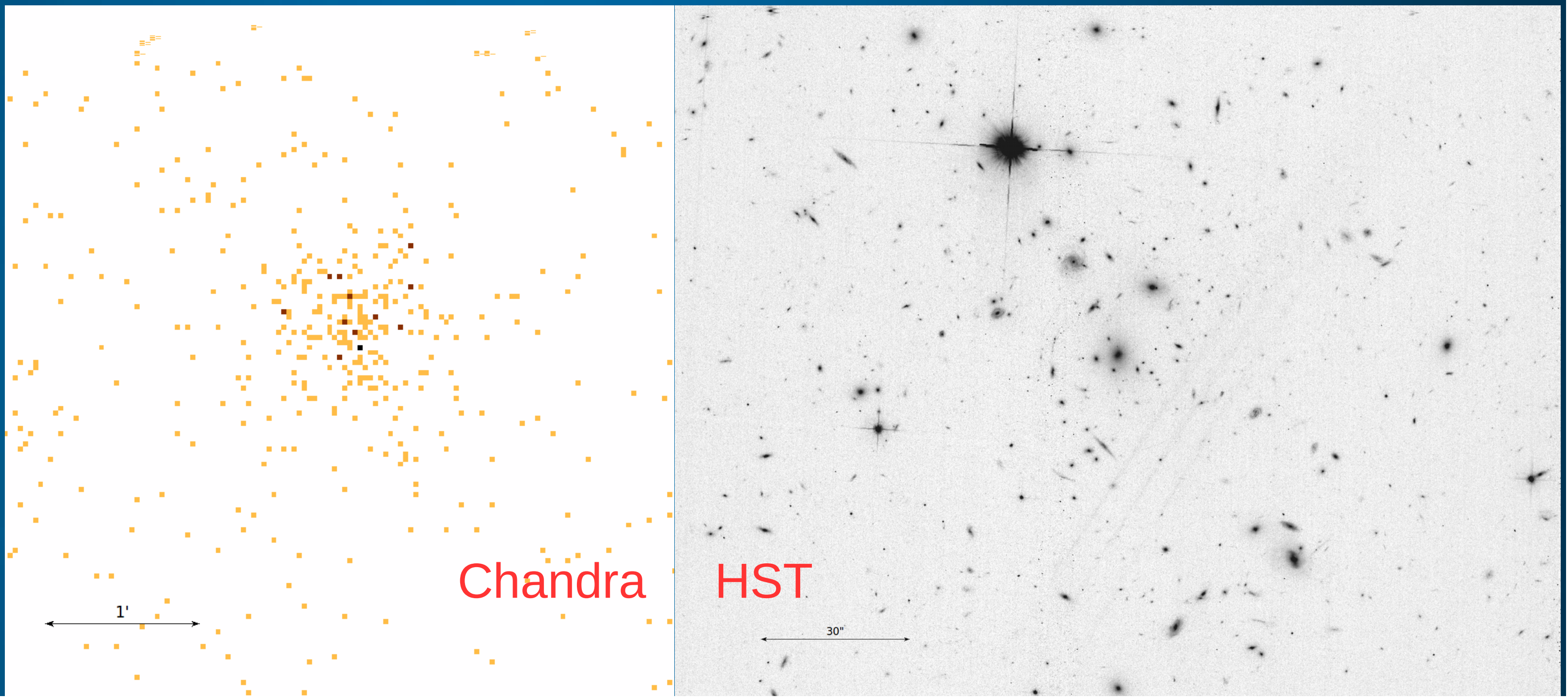
- If you are studying the ICM, select objects to be studied by something independent on ICM at fixed M (such as galaxies, richness, velocity dispersion, etc), and vice versa.
- If you are studying the galaxies, use ICM for selection (as Raichoor & SA 2012, for example).

  Or, be prepared to a complex treatment of the selection function in almost everything you do and that your results depend on assumptions on the missed (unseen) population.

- Even better: if you are studying baryons, don't use baryons for selection, select by gravitational shear, if you can.

The data-rich future: selection by matter, not baryons

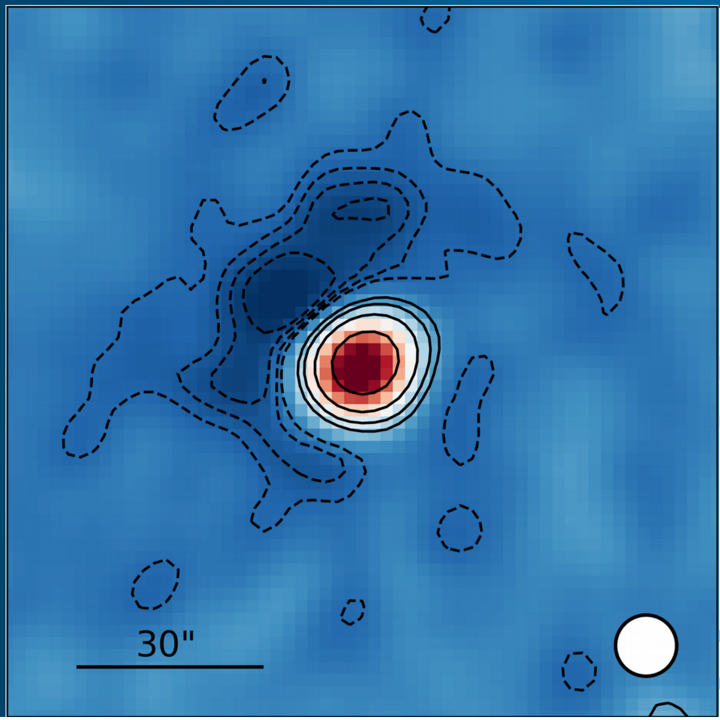
ICM gone in 2011, galaxy dynamics left in past studied. → Started SZ (NIKA2 at IRAM) and X-ray (SWIFT/Chandra) follow-up of the most massive weak-lensing selected clusters in the Hyper Suprime Subaru Survey.



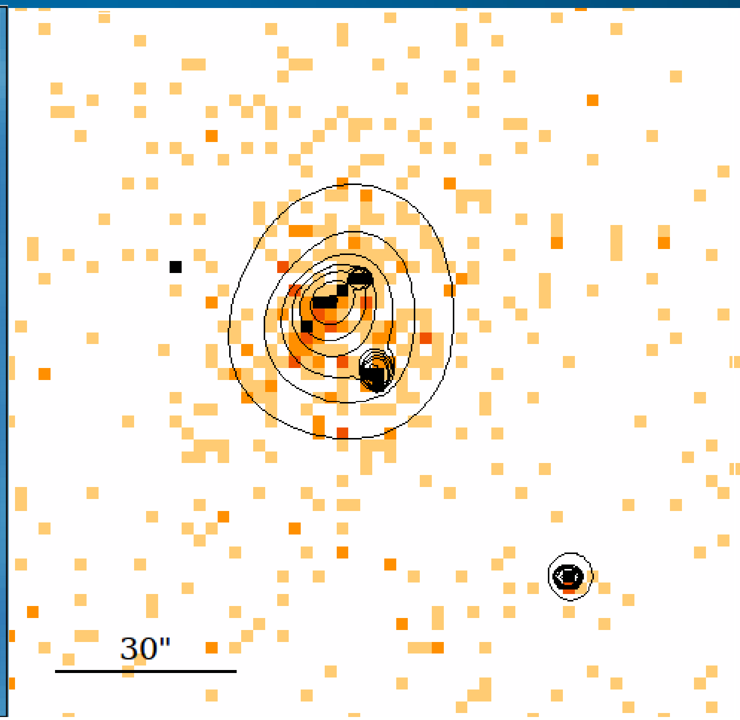
The data-rich future: z=2!

Awarded XMM (and Mustang2) time for the most distant clusters (both non-ICM selected): JKCS041 (z=1.803) and IDCSJ1426 (z=1.75)

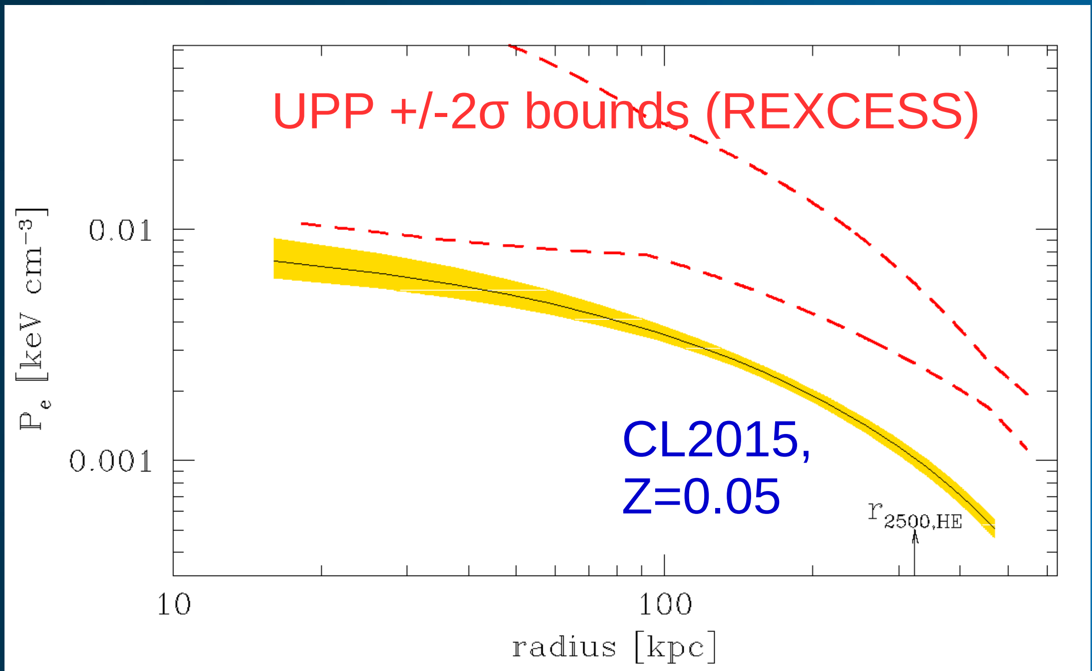
IDCSJ1426 SZ

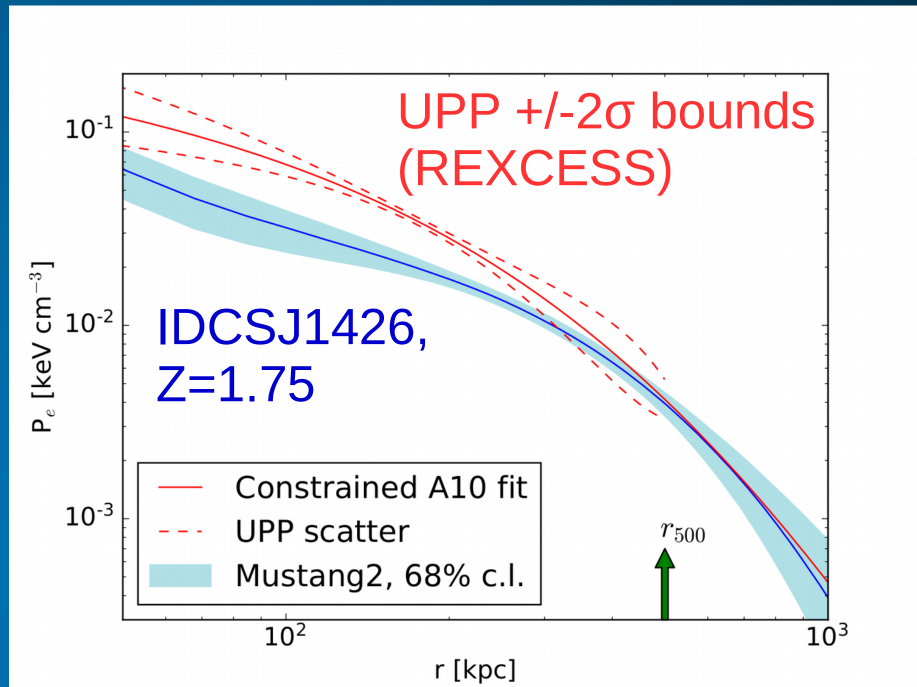


Chandra

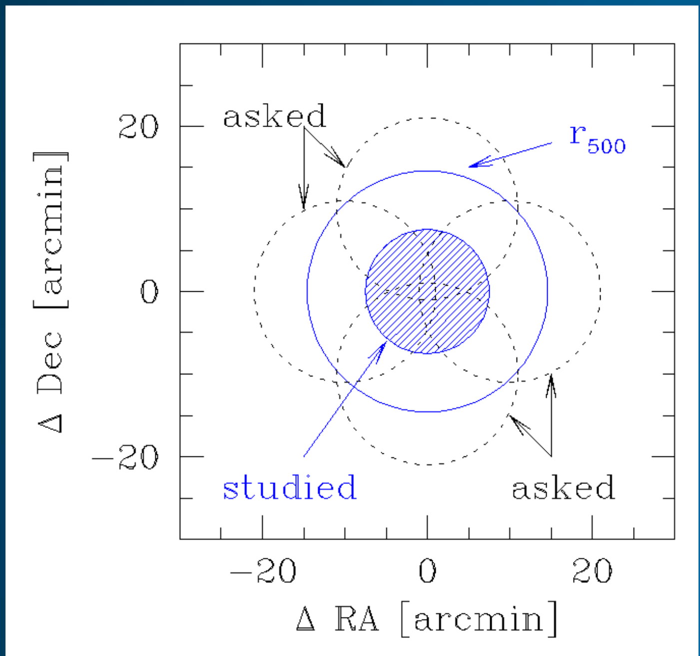


Larger (than believed) variety in pressure profiles, at z=1.75!

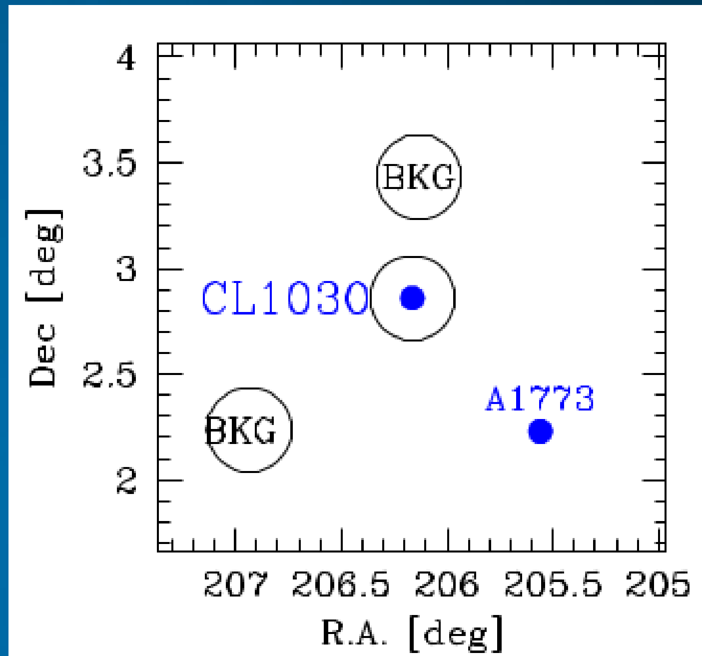




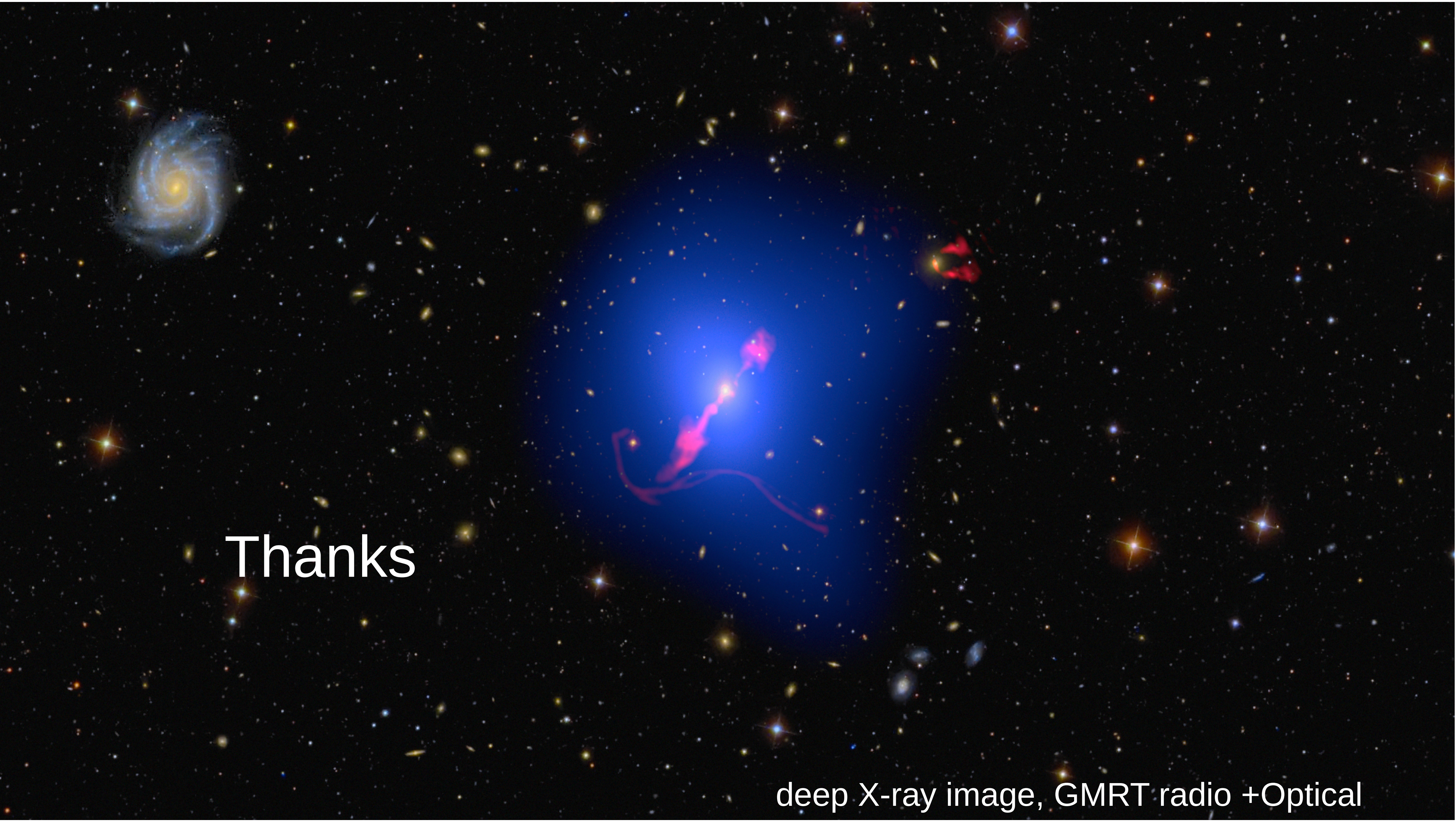
The data-rich future: other deep observations of X-ray faint clusters for their mass



Low-concentration CL2015, got time for a wider view



Outlier because affected by the massive, yet unobserved, A1773 ? Got time on A1773!


Thanks
deep X-ray image, GMRT radio +Optical