X-ray Universe 2014

Sunyaev-Zel'dovich effect
Recent results

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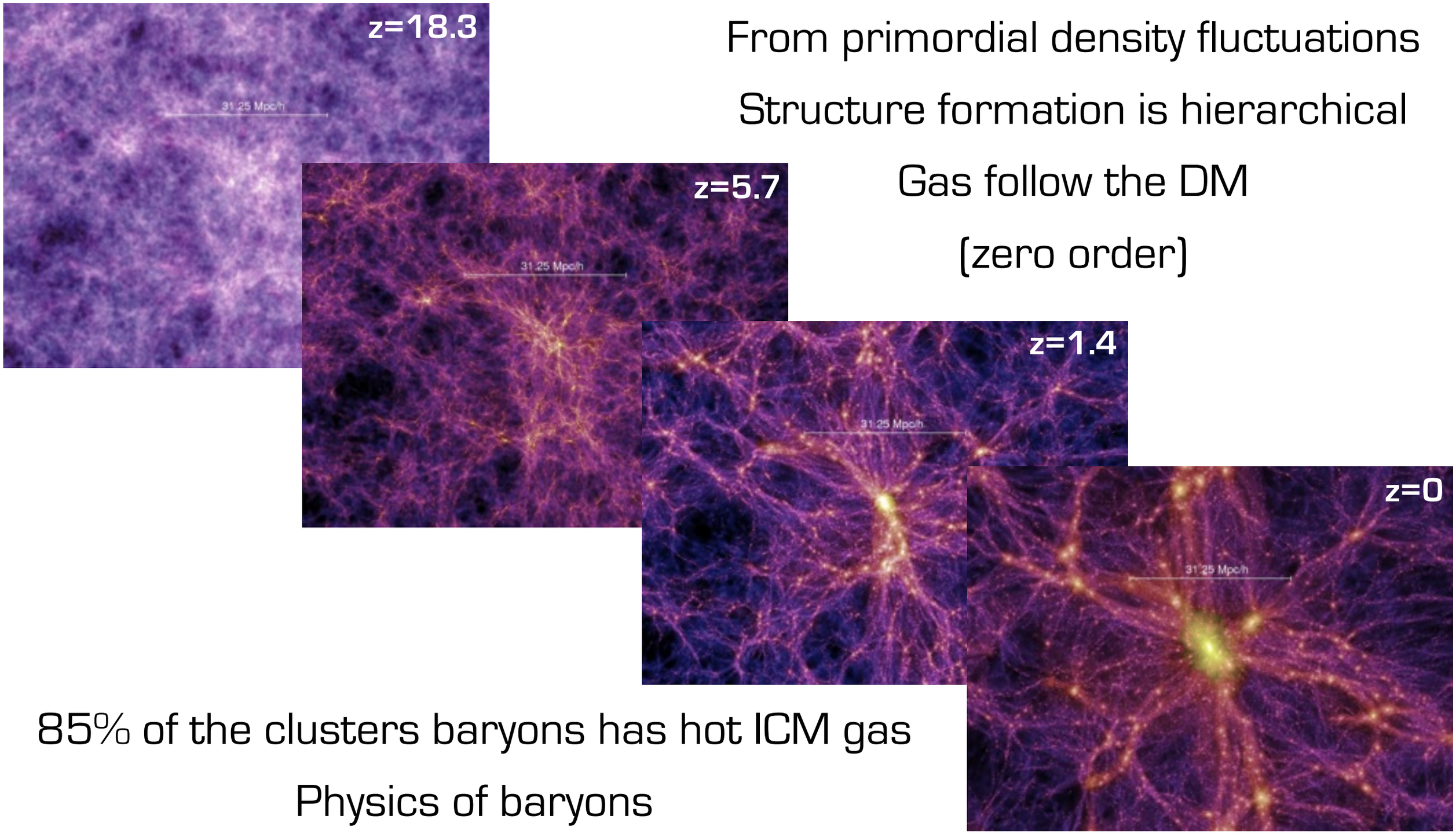
IRAP

(Toulouse, France)

Structure formation



From primordial density fluctuations

Structure formation is hierarchical

Gas follow the DM

(zero order)

85% of the clusters baryons has hot ICM gas

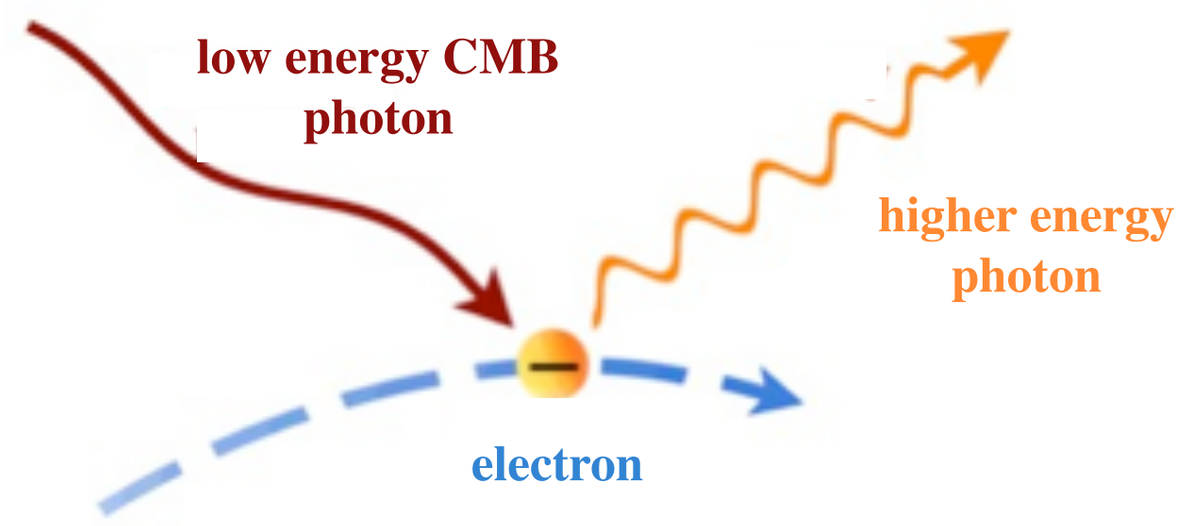
Physics of baryons

(dynamics, feedback, chemical enrichment)

Observing the hot gas in clusters

The SZ effect

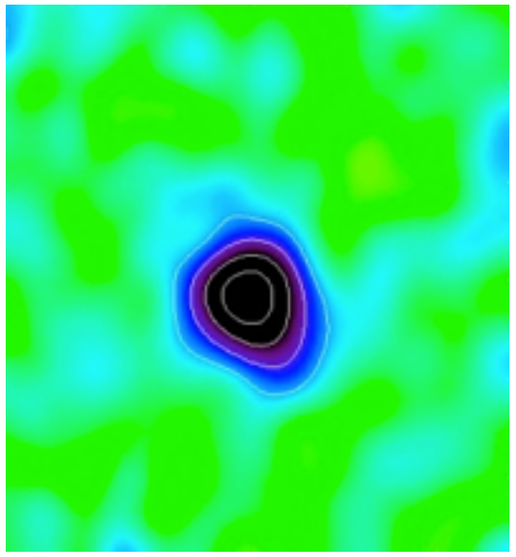
Inverse Compton scattering of CMB photons
by hot electrons
(in the intracluster medium)



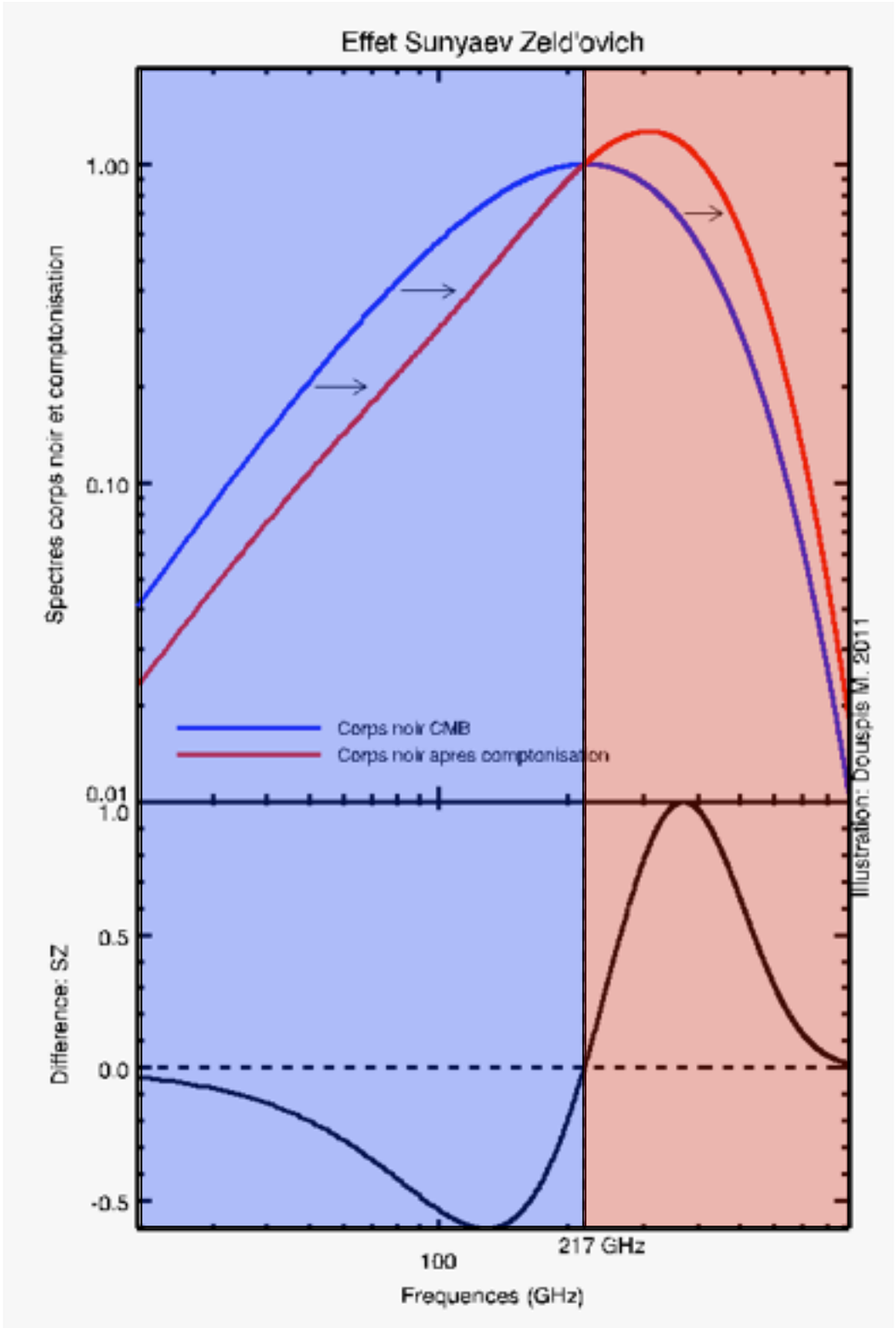
(Sunyaev&Zeldovich+69+72)

The SZ effect

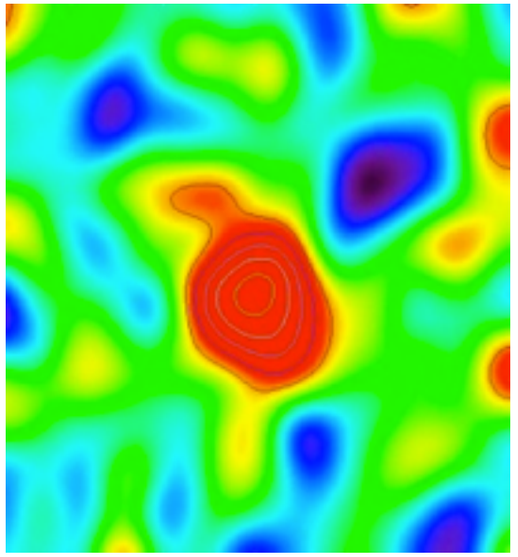
“Hole in the sky”



SZ brightness is independent from z (the SZ flux is not)



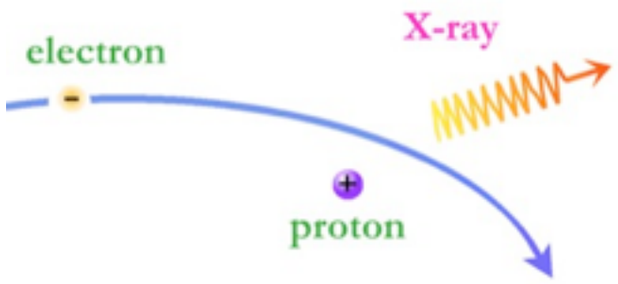
Bump in the sky”

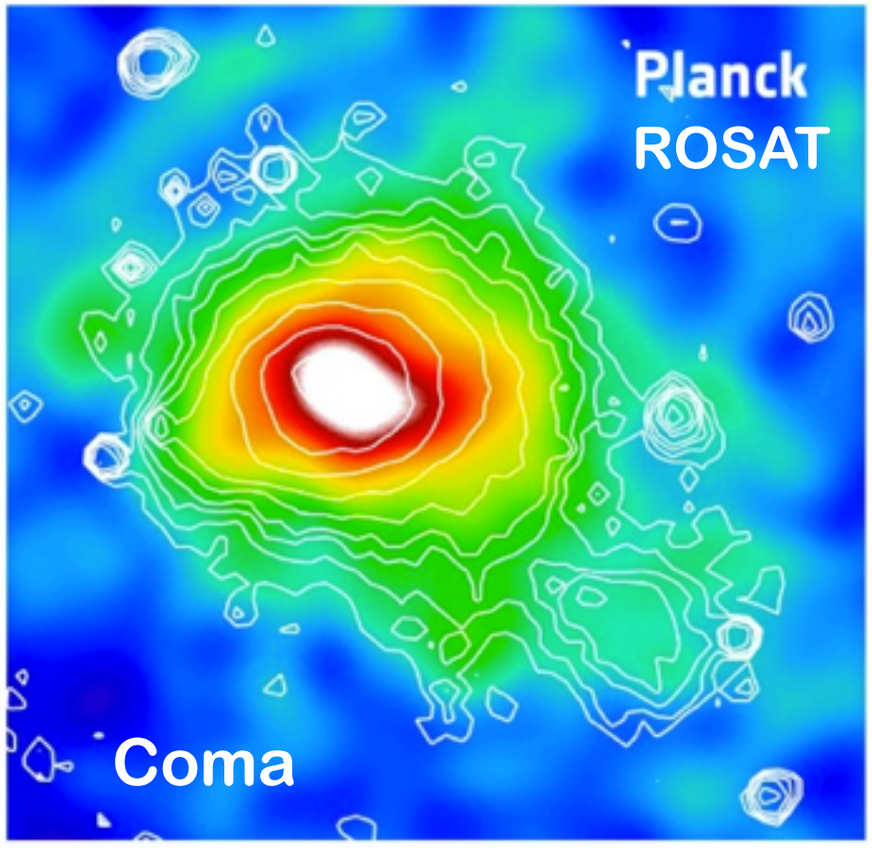


Proportional to the gas content of halos

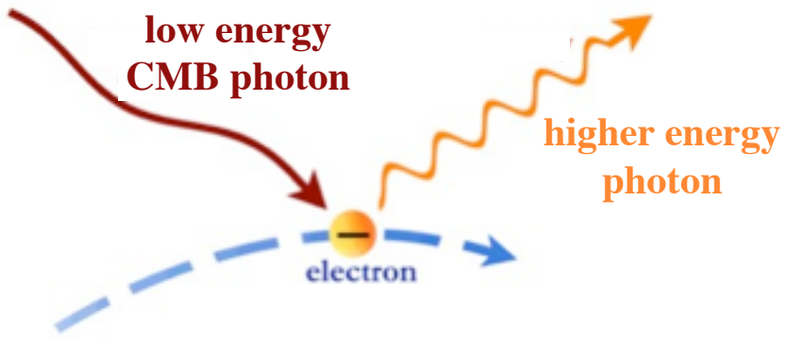
Intra-cluster gas emission

Bremsstrahlung





Inverse Compton scattering



$$E_X \propto \int_V n_e^2 \Lambda(T) dV$$

→ X-ray emission

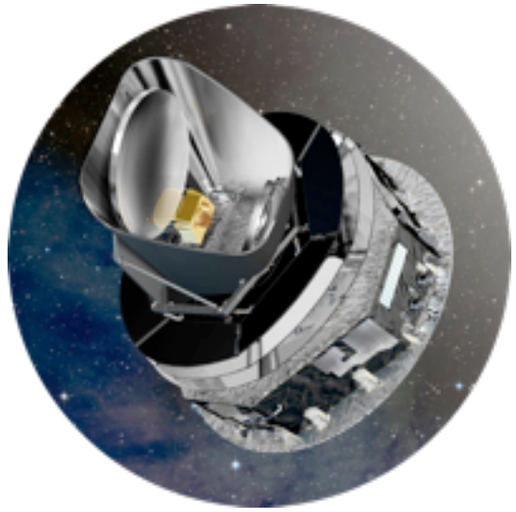
$$F_\nu \propto \int_\Omega (P = n_e T) d\Omega$$

→ Sunyaev-Zeldovich effect

Two independent probes of the same physical component

SZ machines

Planck



Mustang/GBT

SPT

CARMA

Ground-based to space
North to South
10'' to 30'
2cm (15GHz) to 0.3mm (850GHz)
Single dish to interferometers
Bolometers, TES, HEMT

ACT

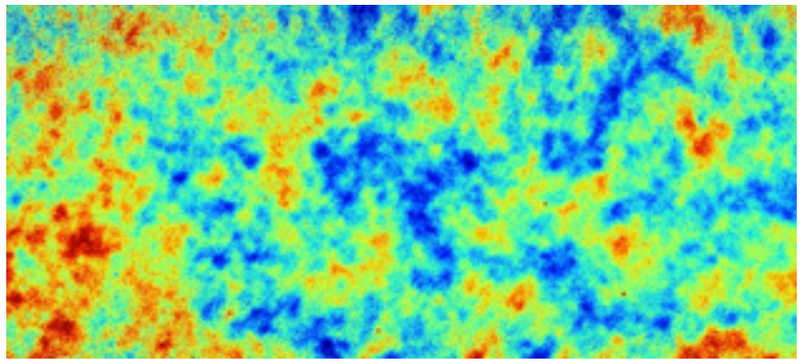
AMI

APEX-SZ

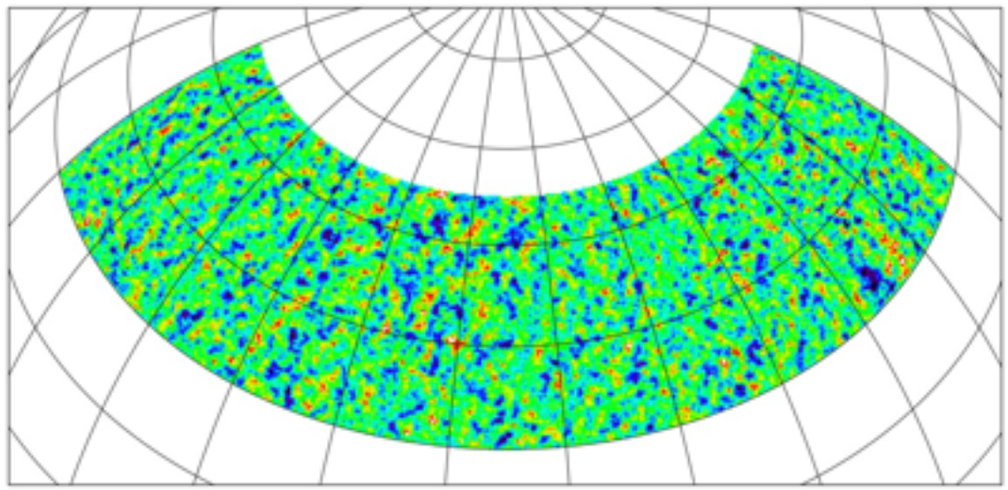
IRAM/NIKA

Clusters in SZ surveys

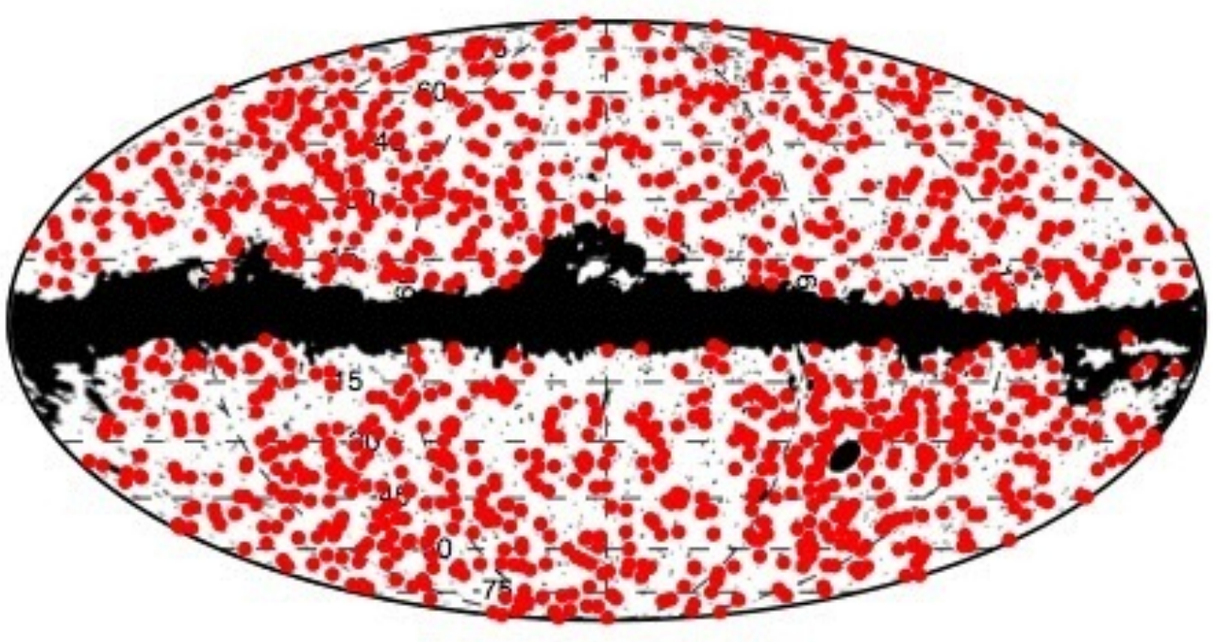
Blind SZ surveys



ACT (Mariage+10, Hasselfield+13)
— 91 new clusters in 780 deg^2 @ 148 GHz / ~1.5'



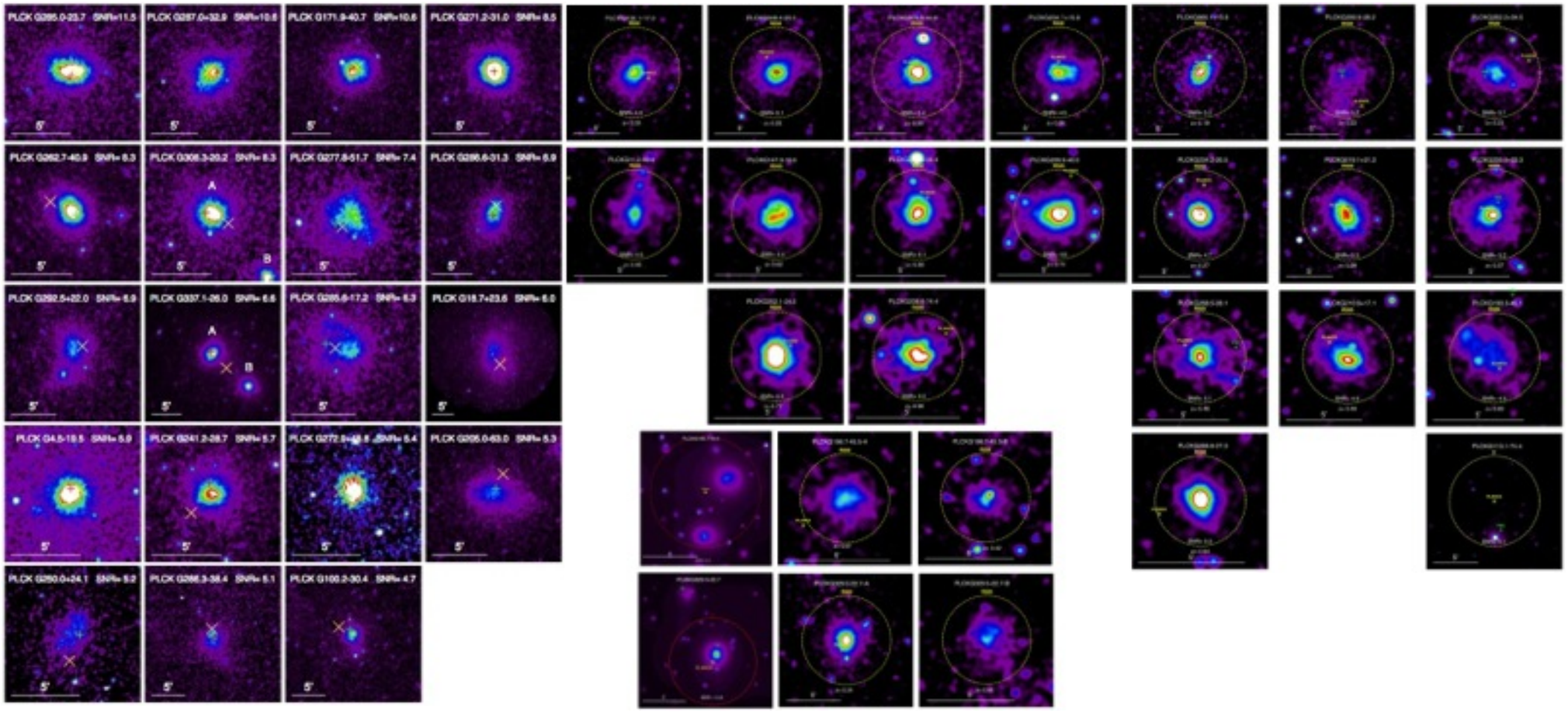
SPT (Reichardt+12)
— 224 clusters and candidates in 720 deg^2 @ 150 GHz / ~1.6'



PLANCK (PC2011 VIII, PC2013 XXIX)
— ESZ, 189 clusters all-sky @ 857-100 GHz / ~5-10'
— PSZ, 1227 clusters and candidates all-sky @ 857-100 GHz / ~5-10'

A powerful X-ray and SZ synergy

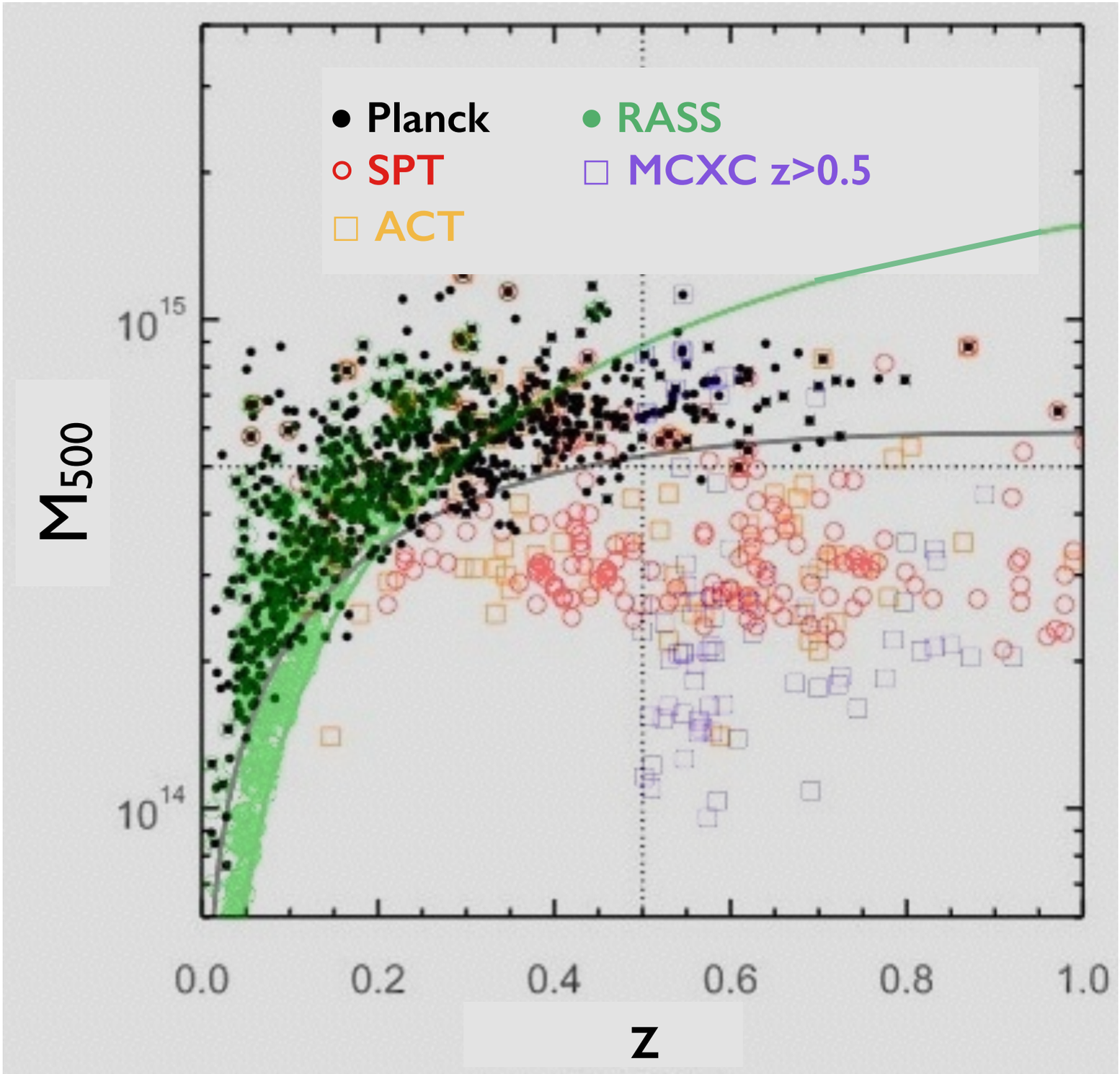
- XMM validation program of Planck SZ clusters ;
- SPT Chandra legacy program



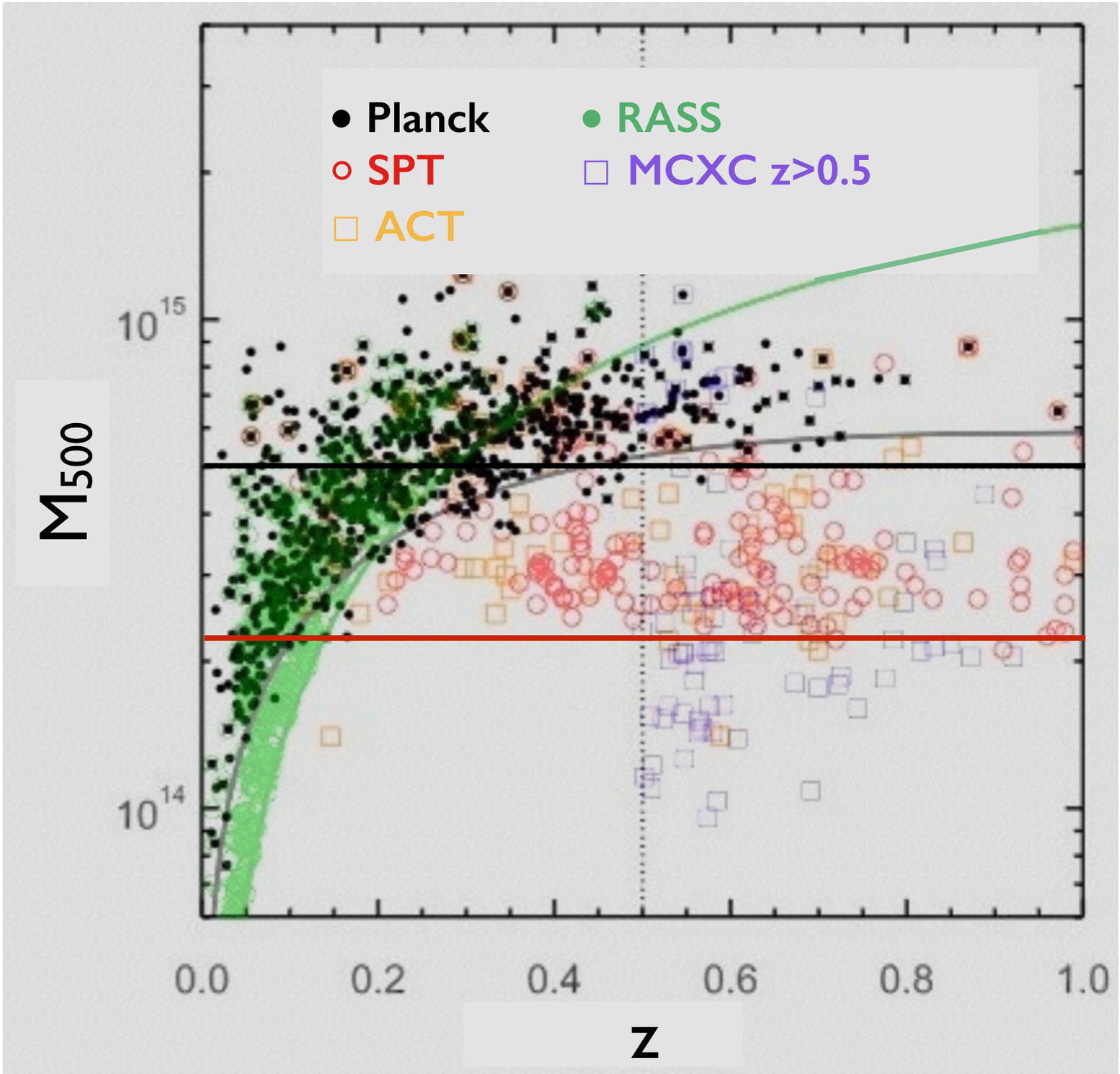
51 observed candidates ; 43 confirmed incl. 4 doubles & 2 triples ;
51 new clusters & 32 good z_X from FeK line

Mandatory performance verification and validation optimisation

SZ and X-ray surveys



SZ and X-ray surveys

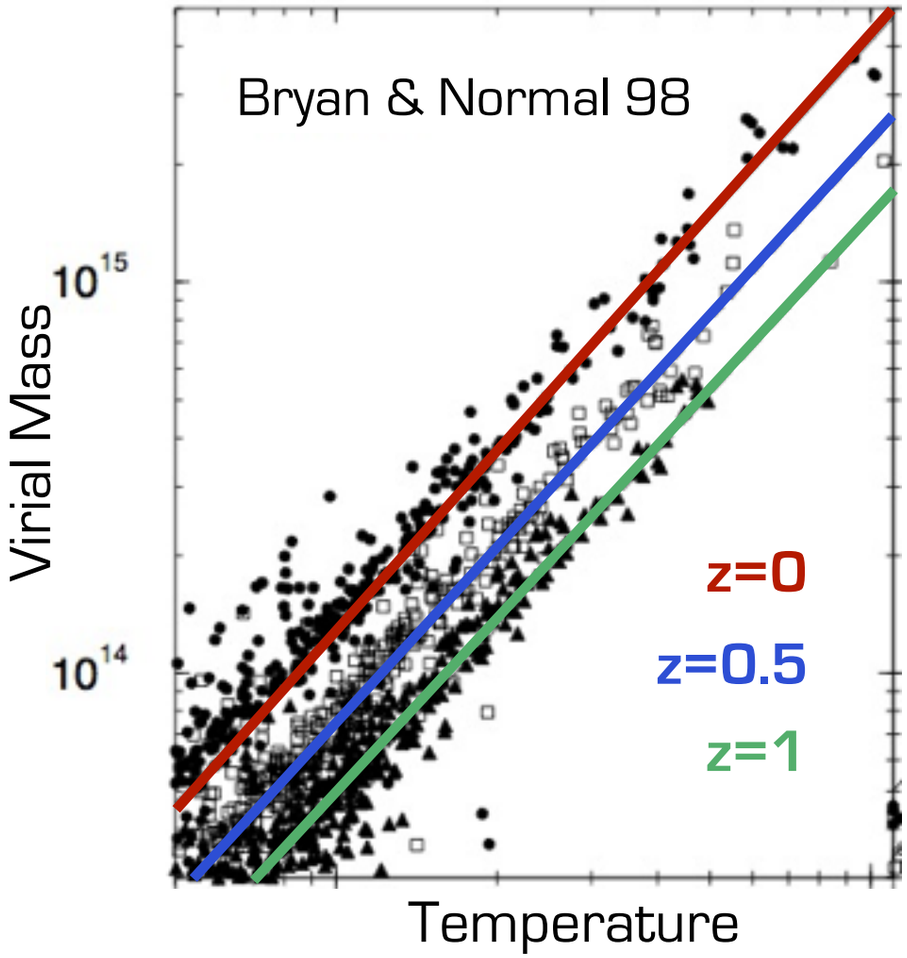


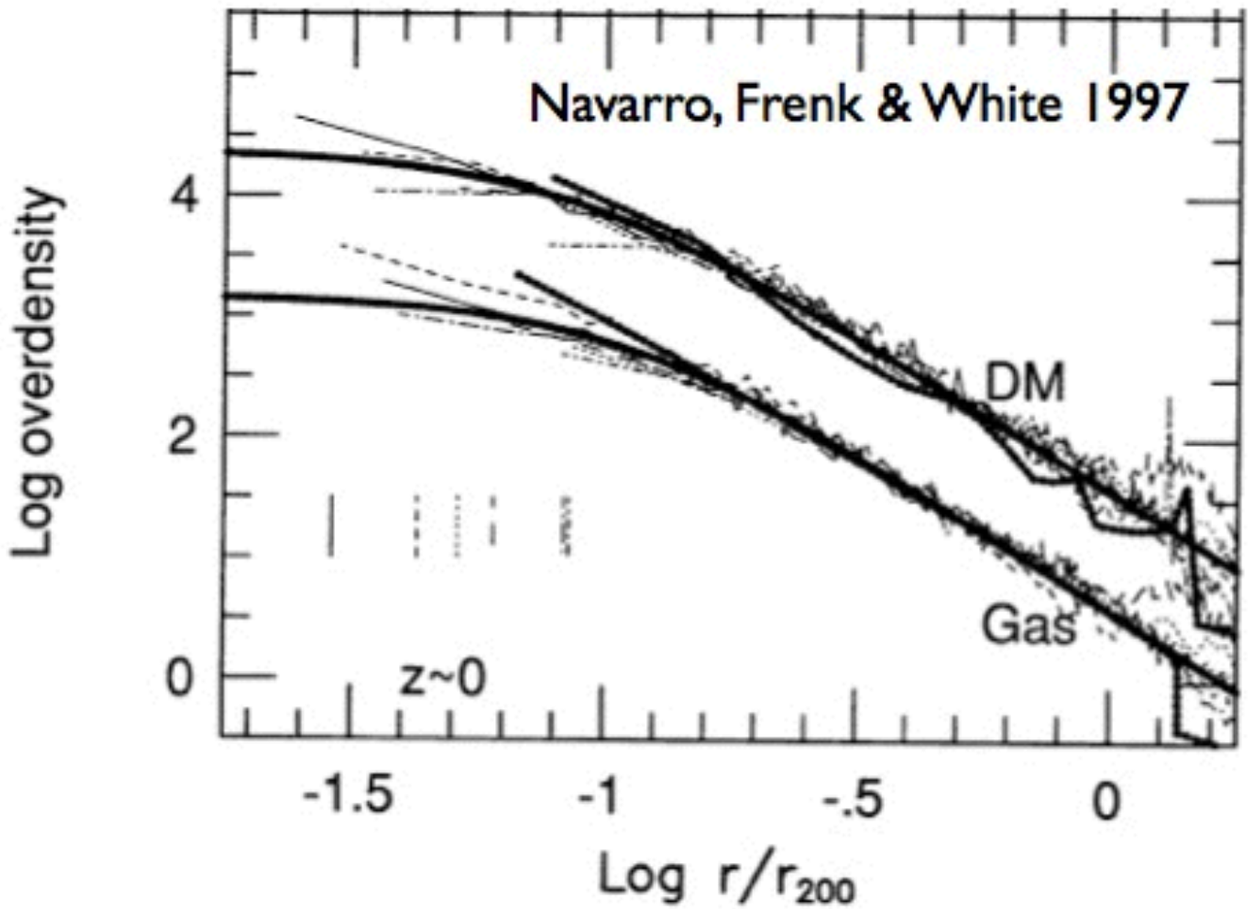
Statistical properties of groups and clusters of galaxies

Formation of structures

Clusters of galaxies form a self similar population of objects

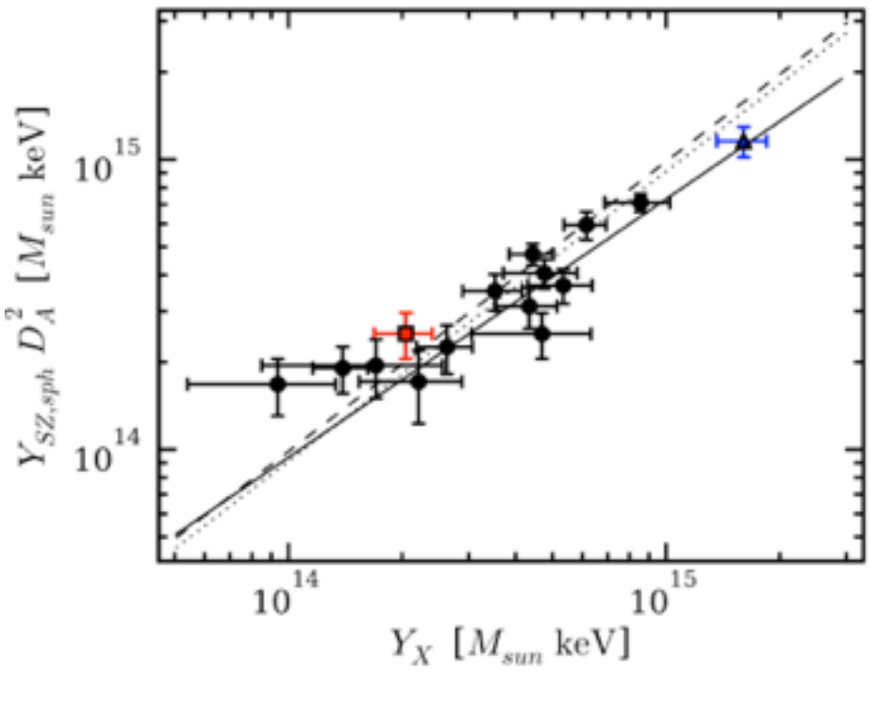
- A two parameters population, i.e., (M,z)
- Similar internal structure





see also, e.g., Bertschinger+85; Kaiser+95; Navarro+95+04; Evrard+96; Voit 05; Arnaud 05

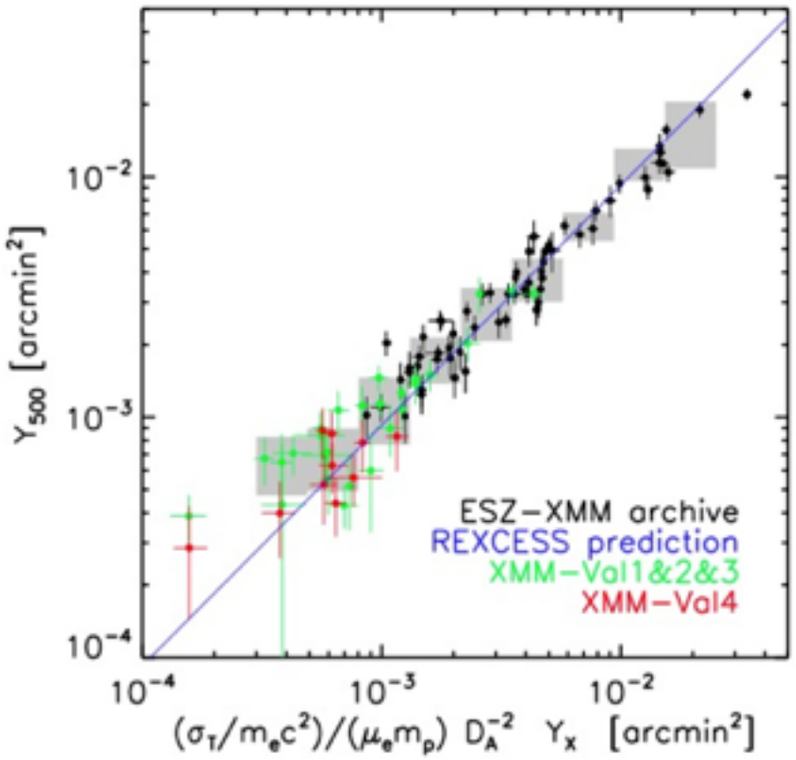
Scaling relations



SPT

15 clusters

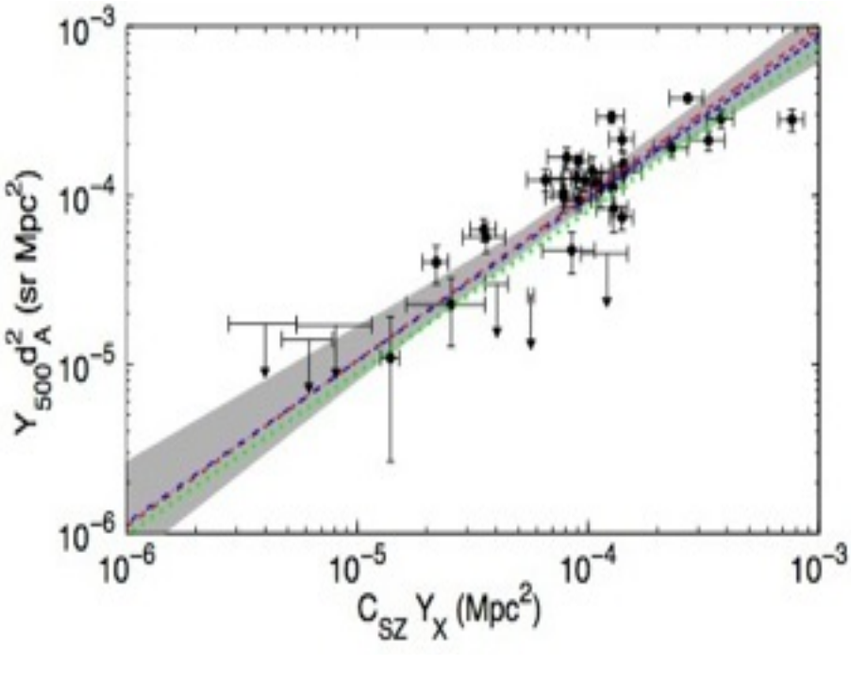
(Anderson+09)



PLANCK

62+36 clusters

(Planck Coll. +11+12)



APEX-SZ

42 cluster

(Bender+14)

see also e.g., Sifon+13, (ACT), Czakon+14 (Bolocam)

Consistent view of the gas content of clusters of galaxies

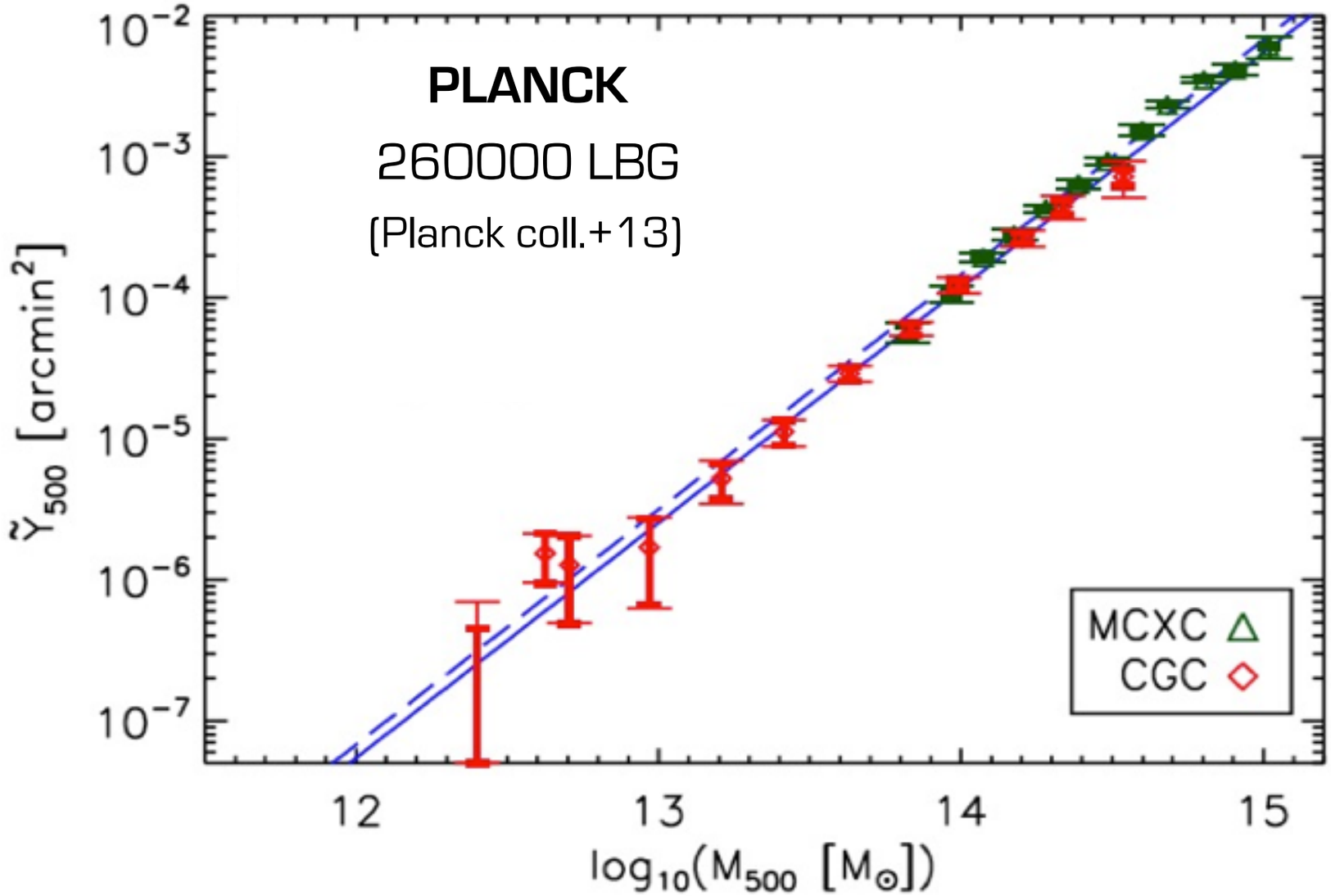
Same behaviour for X-ray and SZ selected clusters

Scaling relations

WMAP
893 clusters
(Melin+10)

PLANCK
1600 clusters
(Planck Coll.+11)

ACT
52 clusters
(Sehgal+11)

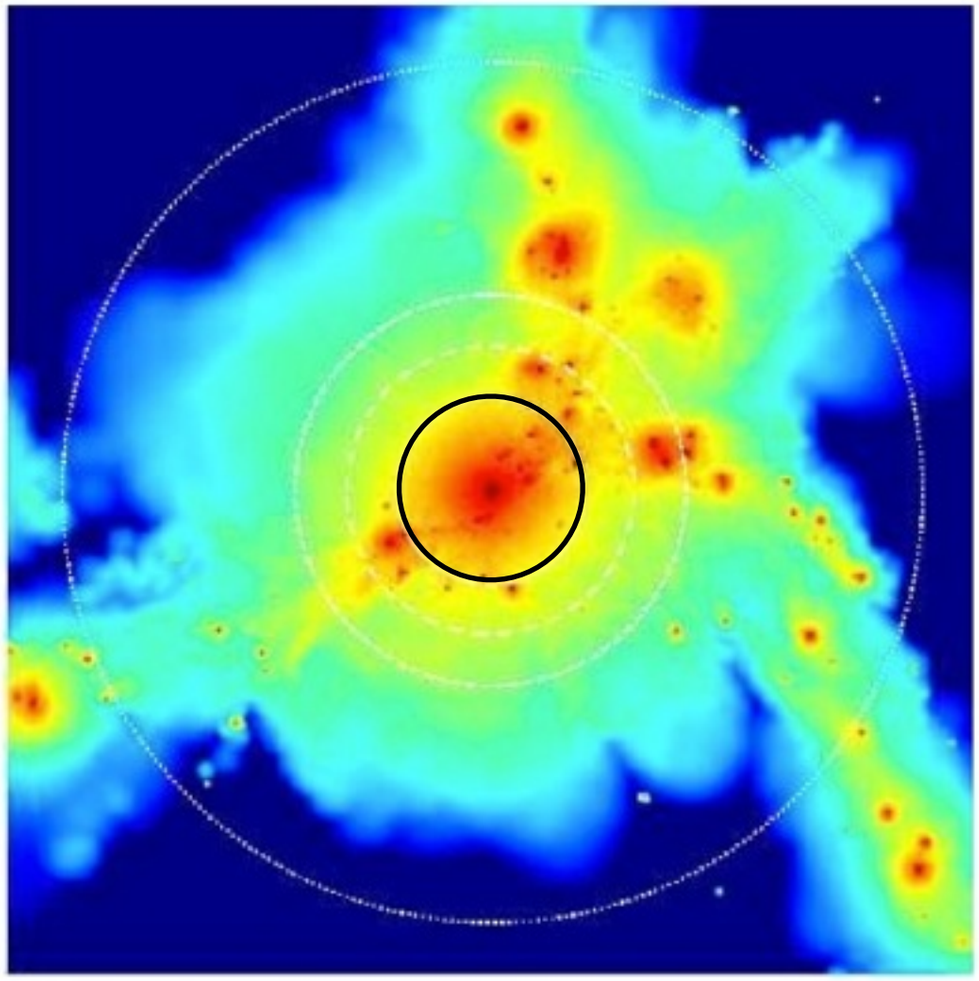


Similarity down to the group and the bright galaxy regime

No missing baryons in clusters (at least within R500)

Census of 25% of baryons as hot gas within halos

Cluster structure to the outskirts



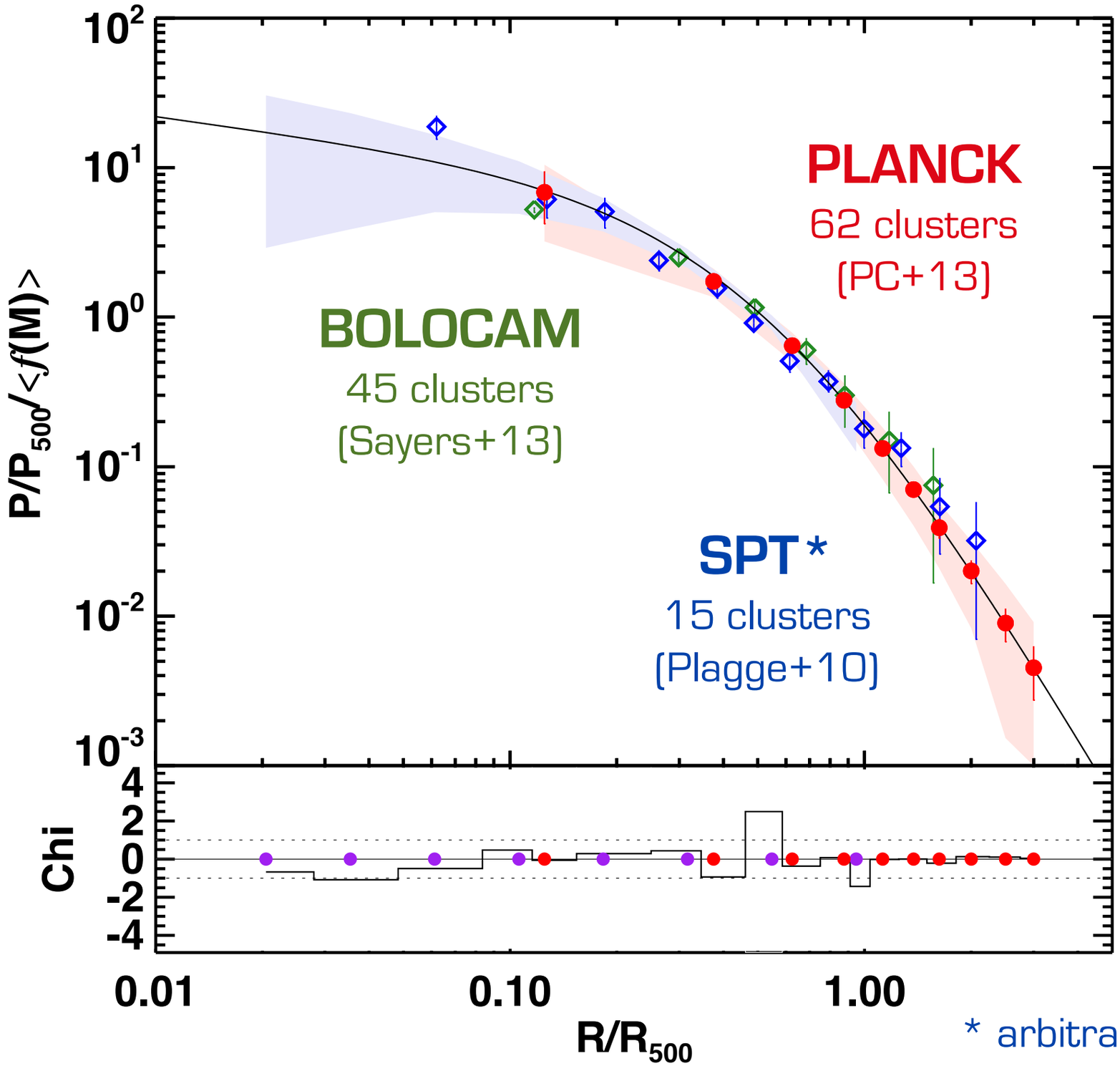
(Roncarelli+06)

R_{500} routinely traced by X-ray

Tremendous effort to reach clusters outskirts with X-rays

see e.g., Urban+10+14, Simionescu+11+13, Walker+12, Eckert+12+13, Sato+12+14, Werner+13, Okabe+14, Reiprich+13(review)

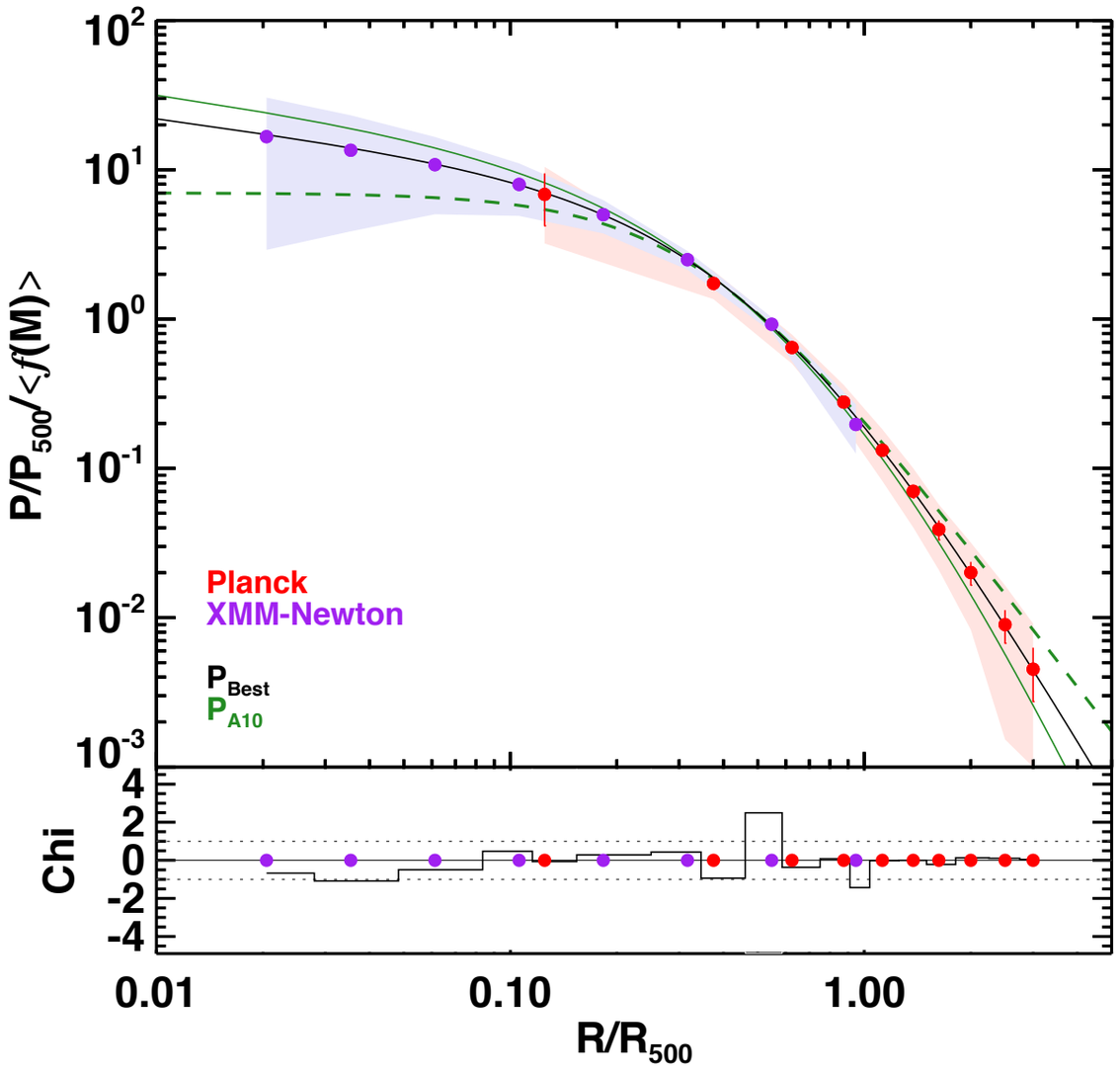
The SZ pressure profile



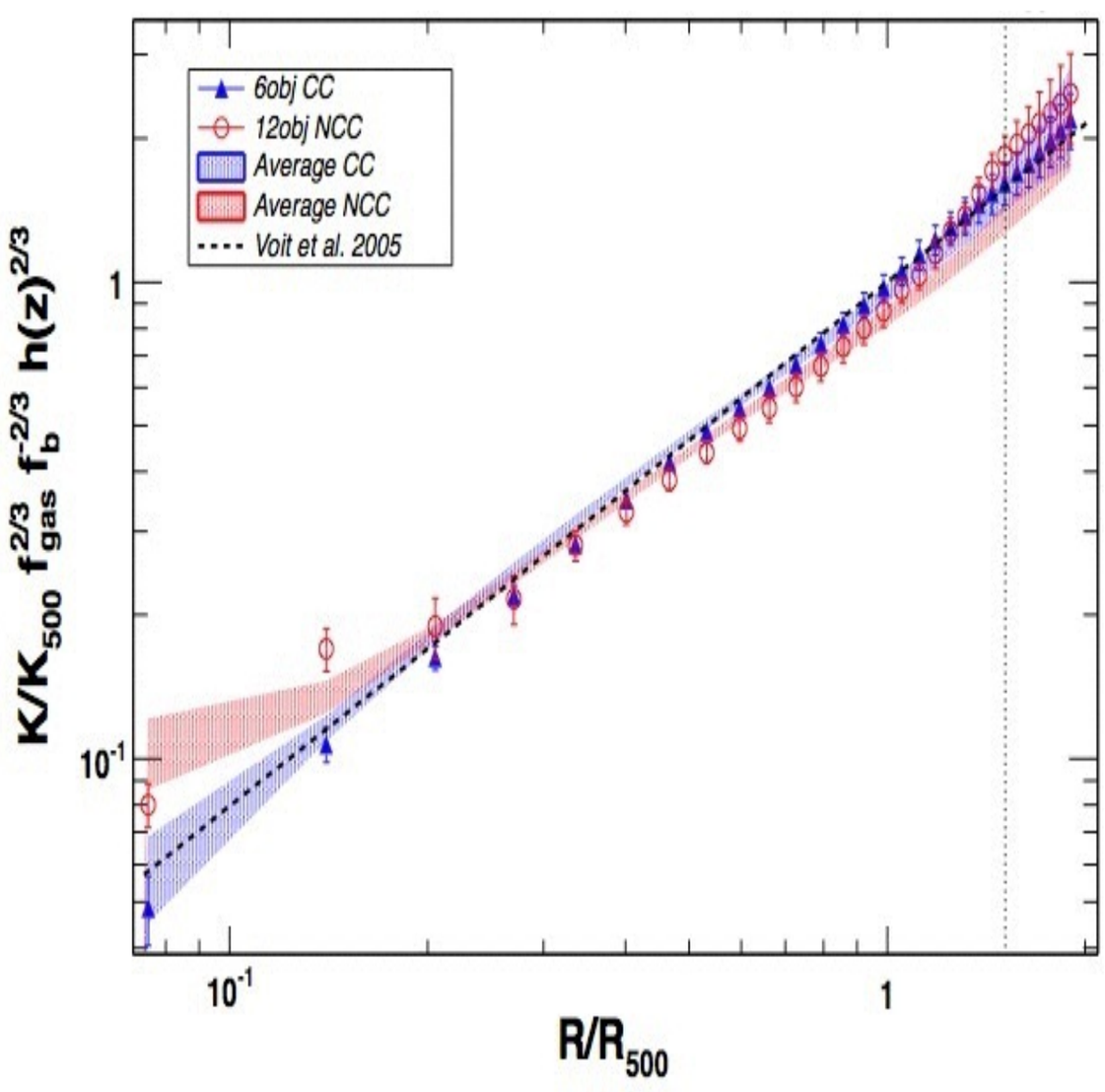
* arbitrarly rescaled

X+SZ structural properties

Coherent view of the gas content properties from joint X -ray and SZ studies from clusters centres to the outskirts



(Planck Coll.+13)

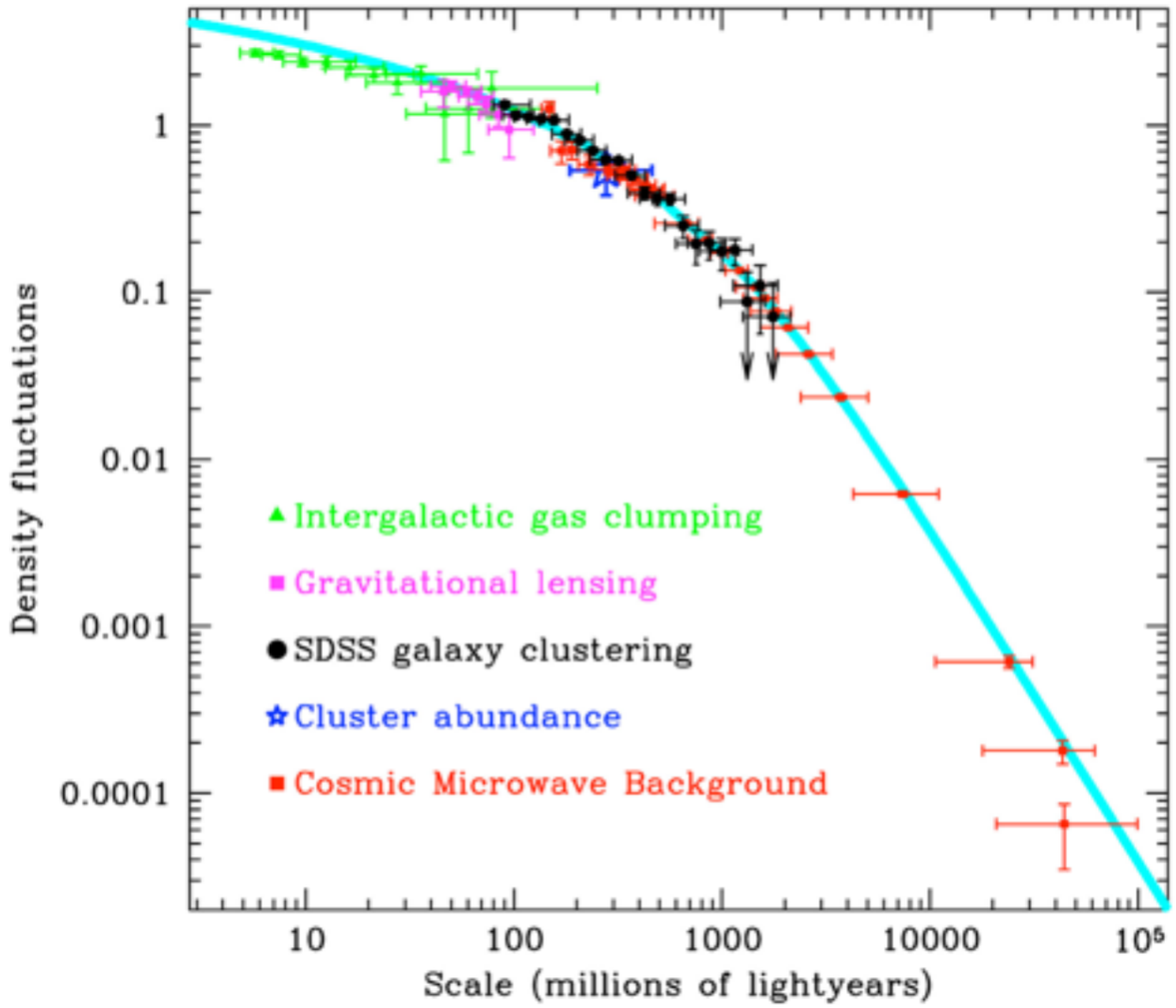


(Eckert+13)

Cosmology with clusters

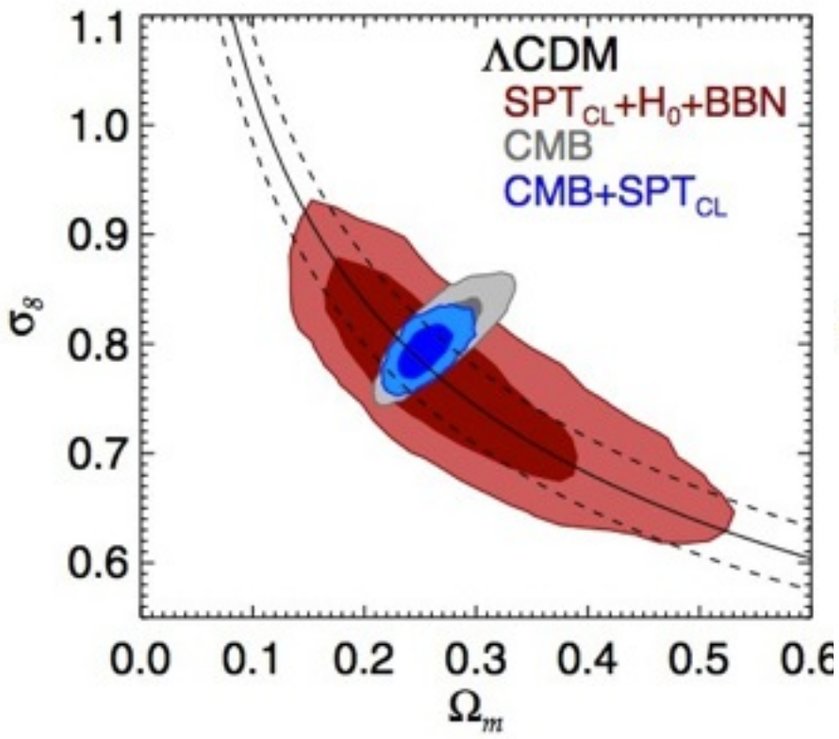
Cosmology

The clusters mass function and its evolution, i.e., N(M,z), strongly depends on the content in matter and energy of the Universe

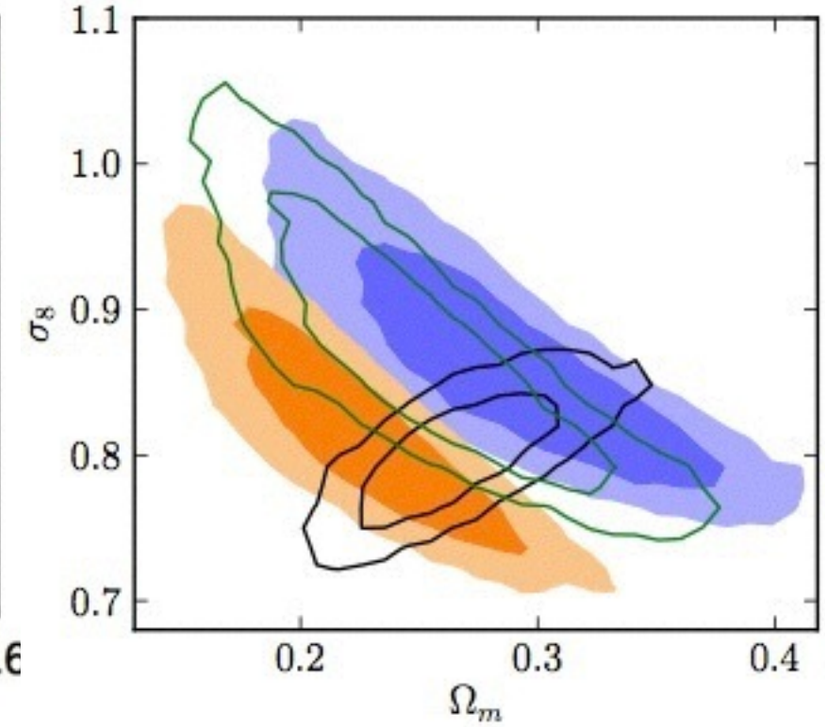


(from M. Tegmark)

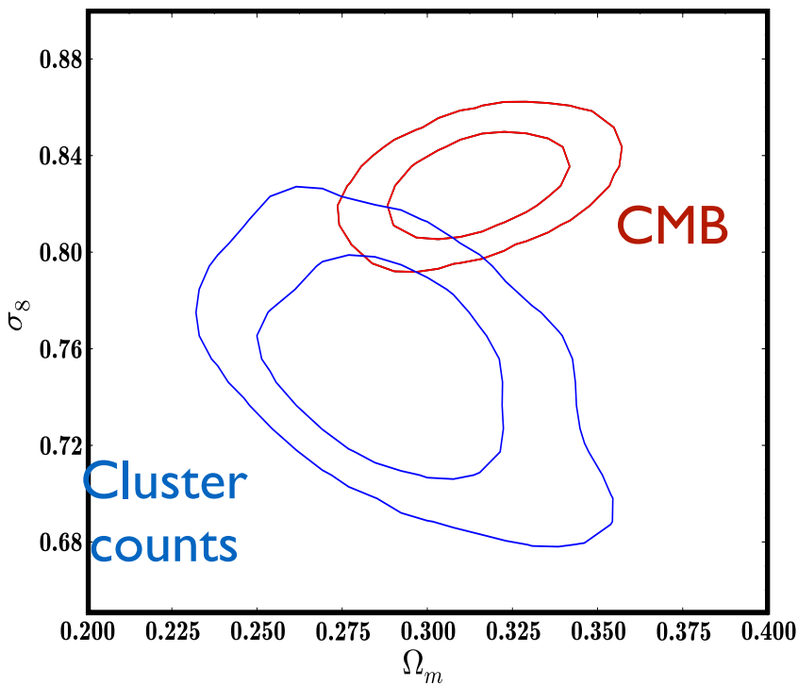
Cosmology



SPT
(Benson+13)



ACT
(Hasselfield+13)



Planck
(Planck Coll.+13)

Overall agreement between SZ measurements

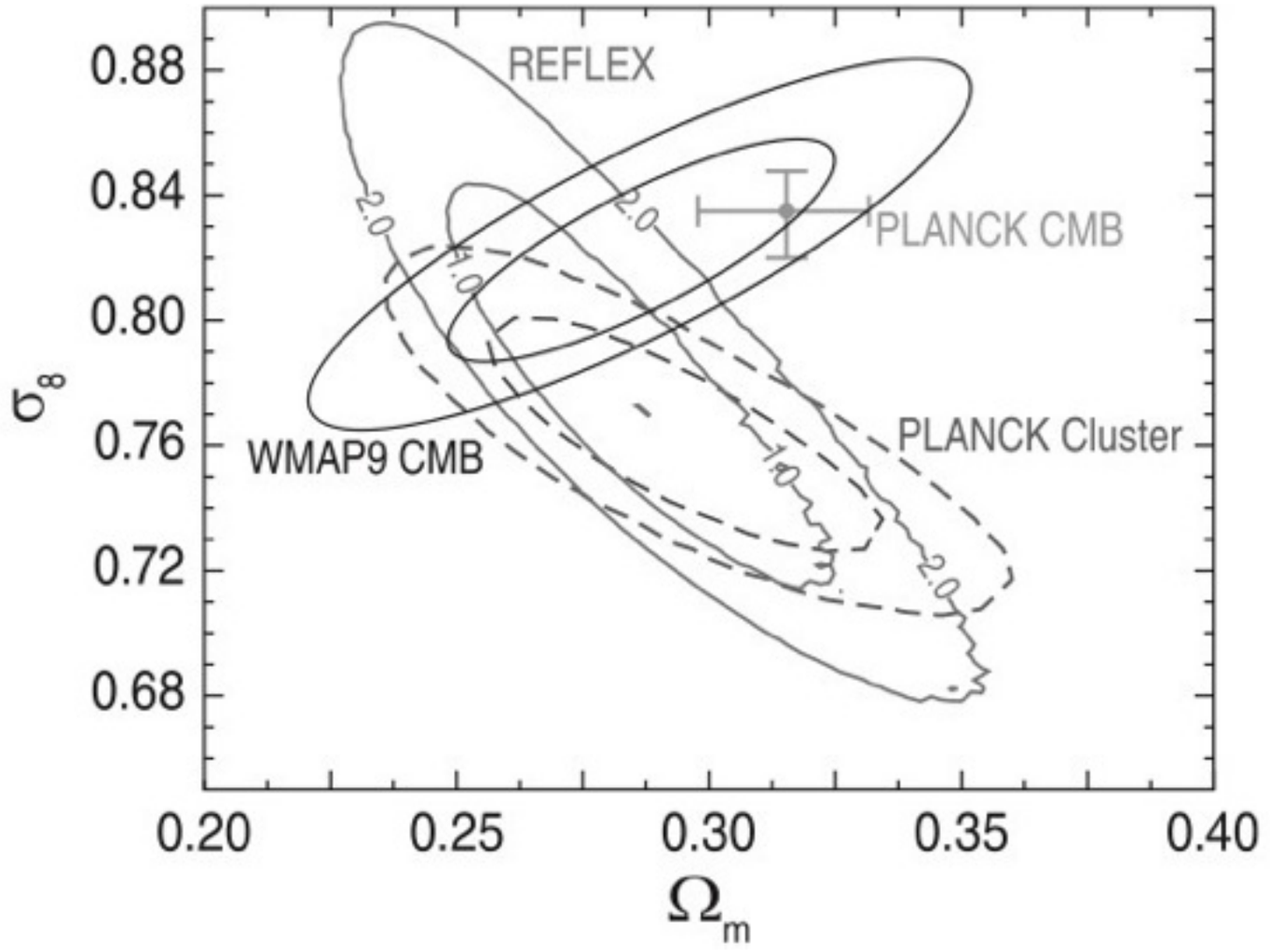
Convergence or tension with CMB ?

Cosmology

Possible source of bias

- Calibration of scaling relations (mass proxy)
- Impact of the baryon physics (e.g., turbulence, bulk motion, baryons acceleration in clusters outskirts)
- Cross calibrations (X-ray and SZ instruments)

Böhringer+14



Overall convergence between X-ray and SZ constraints

see e.g., Kitayama+13, Hajian+13, Hasselfield+13, McCarthy+14, Cusworth+14, Schellenberger+14, Nelson+14

The prospects for SZ observations

Distant clusters

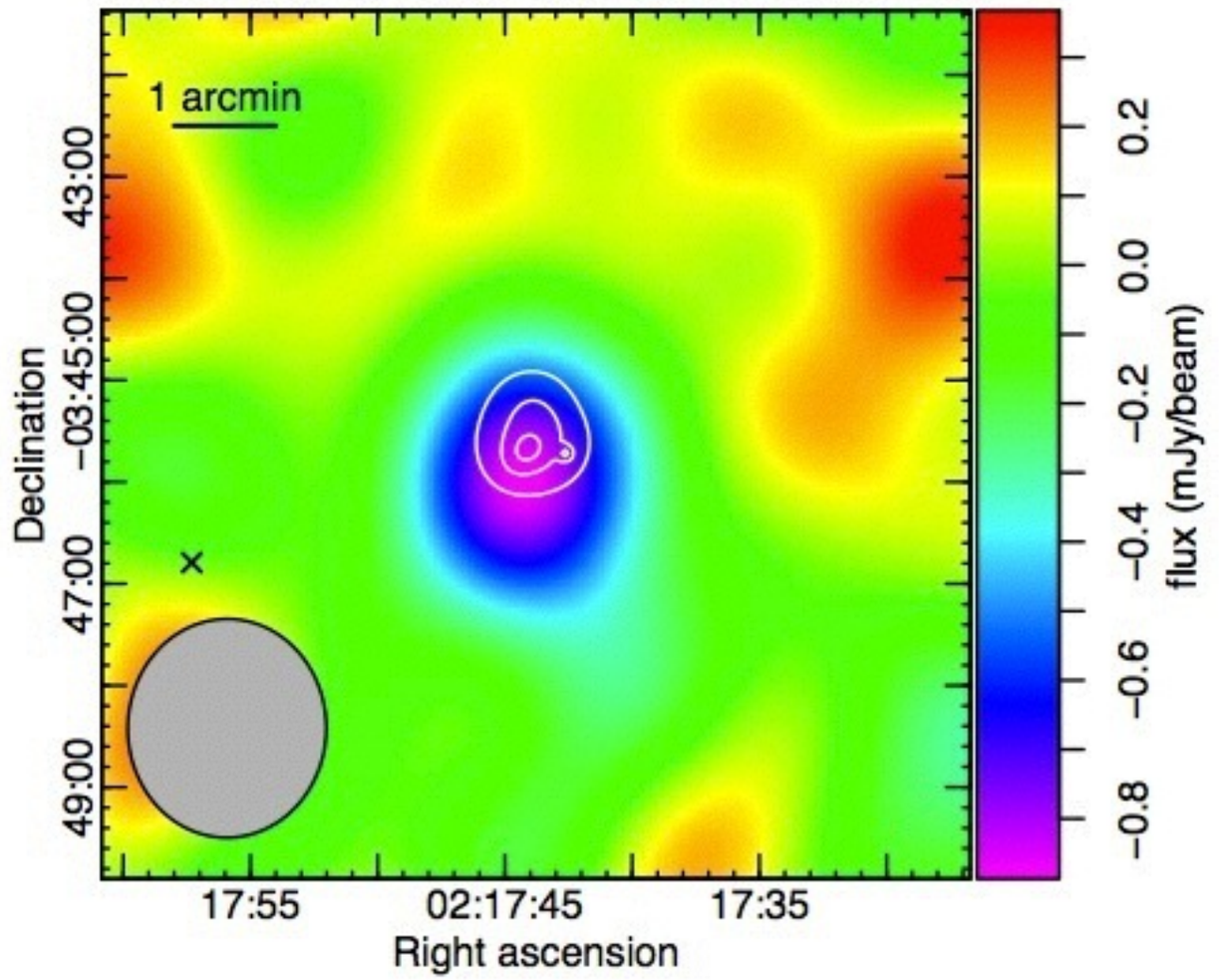
X-ray detected

XLSSU J021744.1−034536

$z = 1.9 \pm 0.2$

CARMA

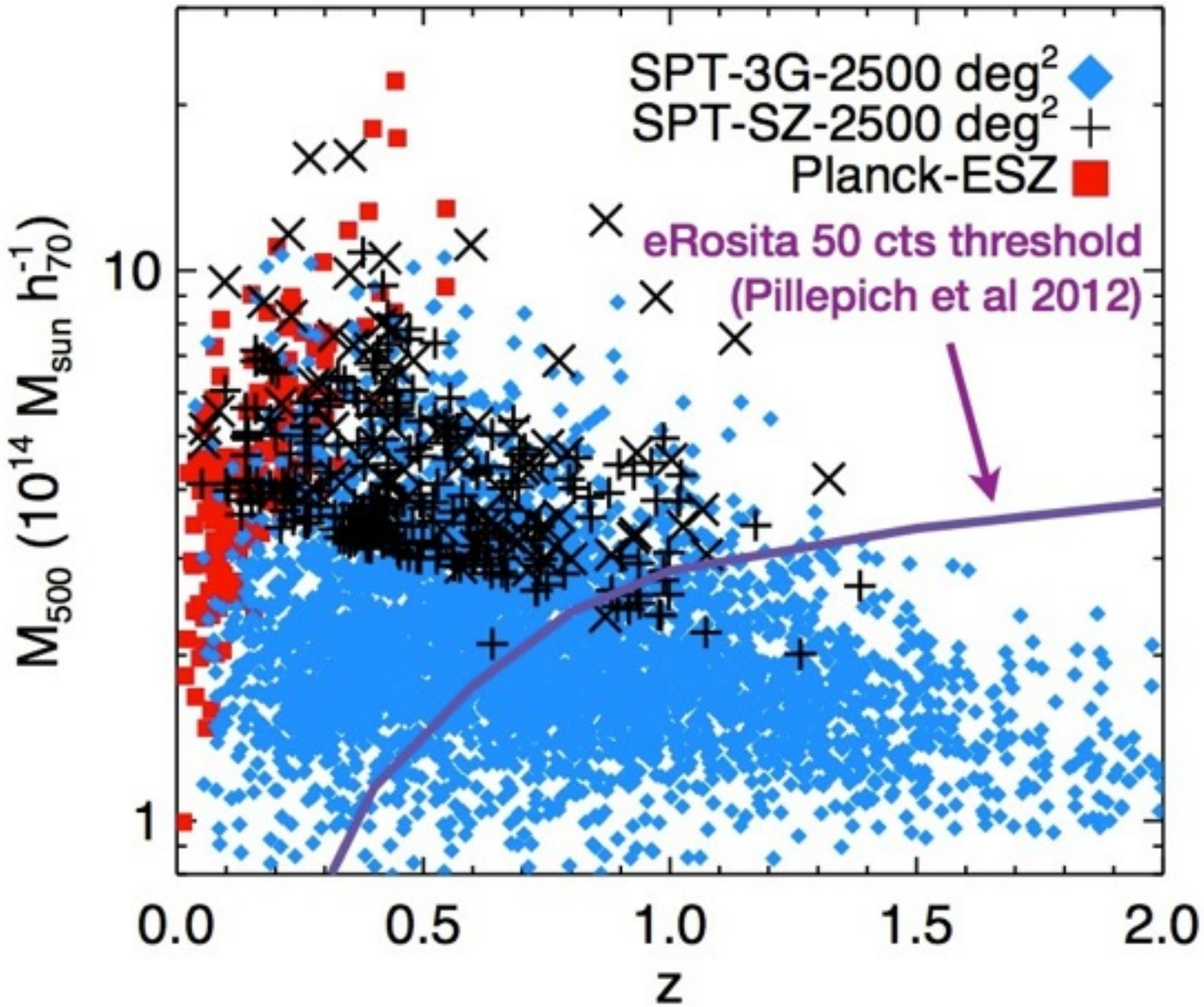
(Mantz+14)



see also e.g, Brodwin+12, Stalder+13, Bayliss+14

Distant clusters

Important the legacy of the Planck, SPT and ACT surveys



SPT-3G

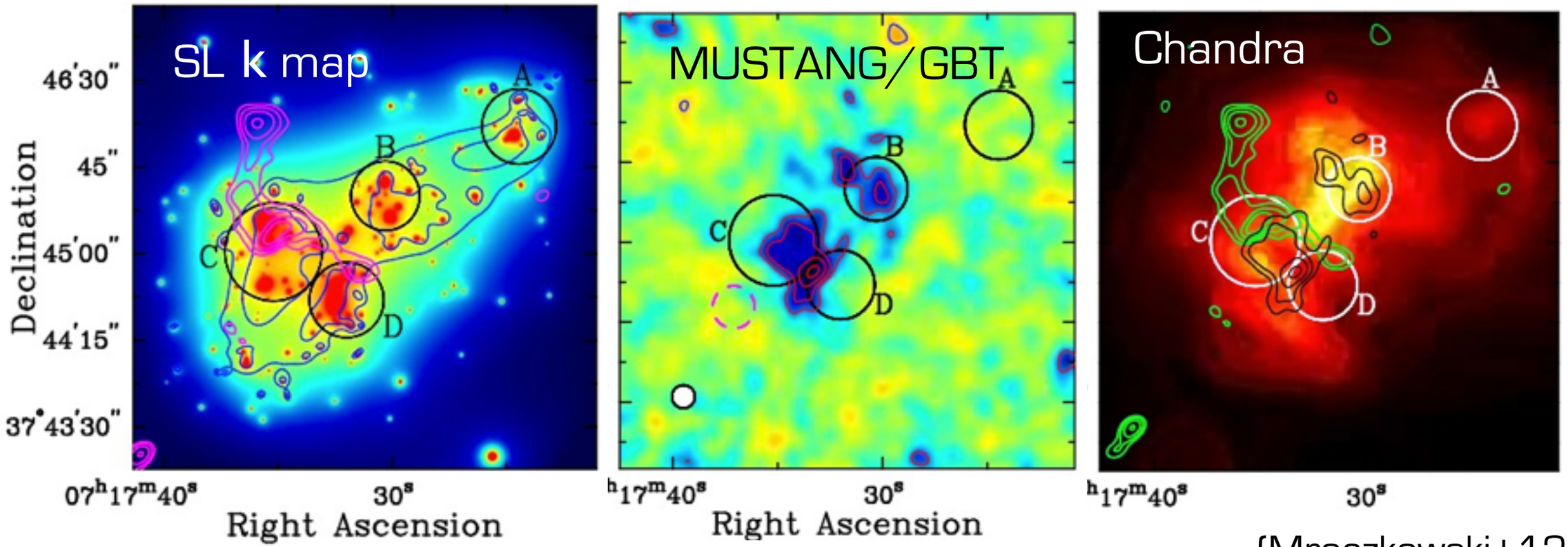
(Benson 12, 2nd eROSITA worshop)

Cluster physics

Complex dynamics of a triple merger system MACS J0717.5+3745

Combine Mustang & Bolocam SZ data + X-rays/Optical

SL (Zitrin+09, Limousin+09) ; Light distribution (Ma+09) ; Radio (van Weeren+09)



(Mroczkowski+12)

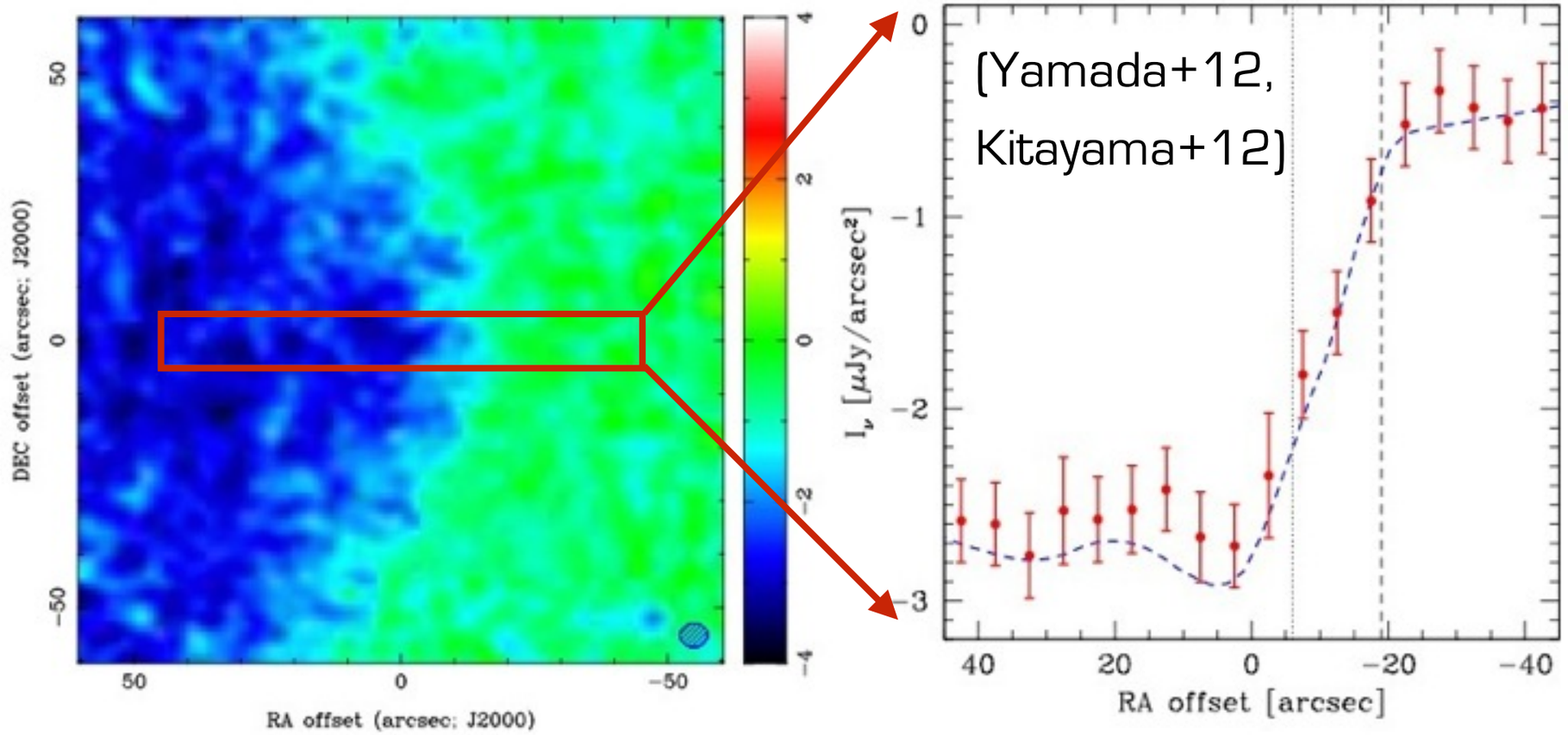
Cluster physics

Current high spatiale resolution SZ instruments

Mustang/GBT	CARMA	NIKA-2/IRAM
13”	11”x17”	18.5”
(Korngut+12)	(Plagge+12)	(Adam+14)

ALMA @ 5”

Shock front in the bullet cluster (simulation at 90GHz)



Conclusions

- Large catalogues of clusters from SZ surveys complementing the X-ray catalogues and providing mass limited samples

- Consistent X-rays and SZ view of the hot gas content and properties of clusters (at least within R_{500}) over a wide range of masses.

- Clusters are a valuable cosmological probe providing that the physics of their baryons is properly understood.

- The future of SZ observations likely lies on the ground with “high” spatial resolution

- Important legacy value of the current SZ surveys (Planck, SPT and ACT).