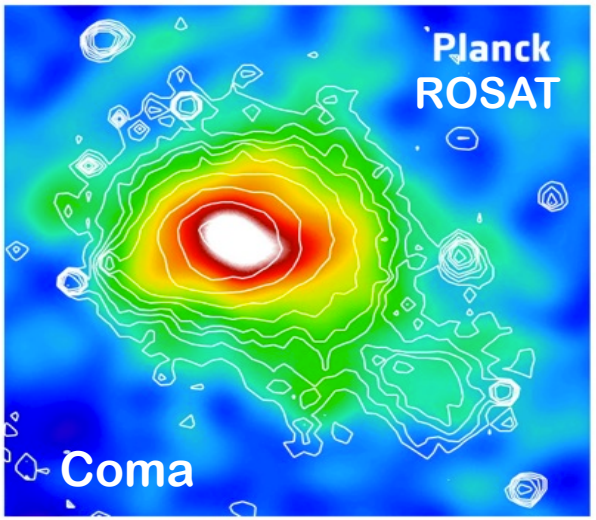
The SZE view of Galaxy clusters and cosmology

M. Arnaud (CEA-Service d'Astrophysique)

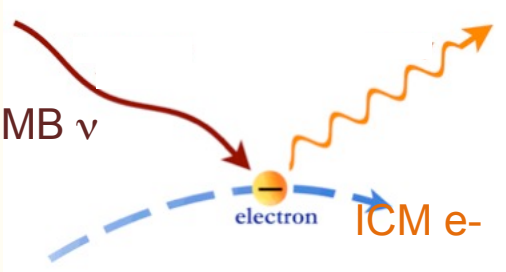
On behalf of Planck collaboration for Planck related results

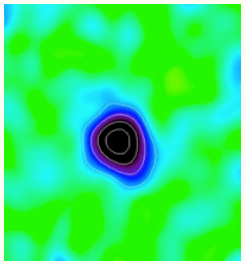
The Sunyaev-Zeldovich effect

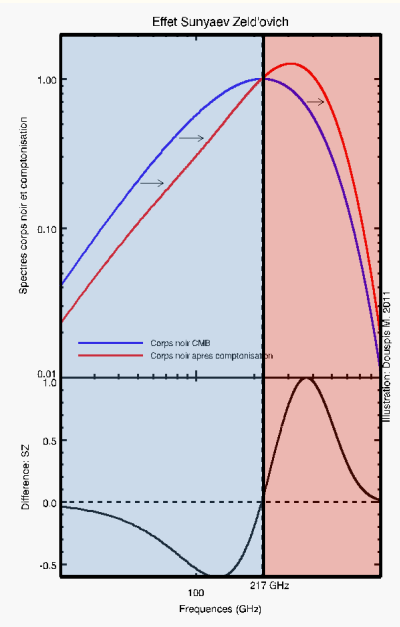


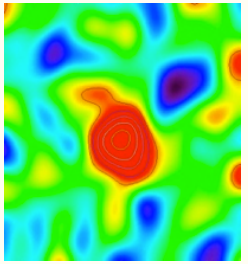
Planck Early Results, IX, 2011

Inverse Compton scattering









Probing
the ICM component (as X-ray)

Brightness is independent of z

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

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

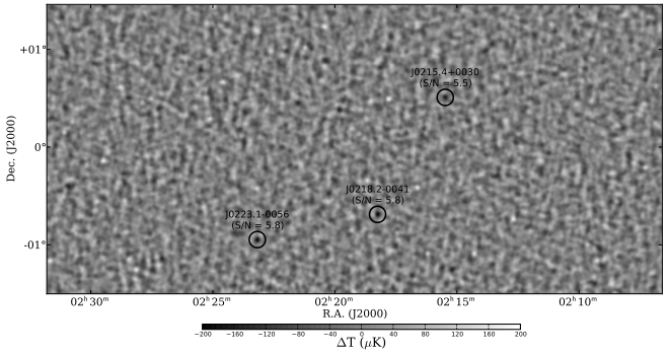
Amiba

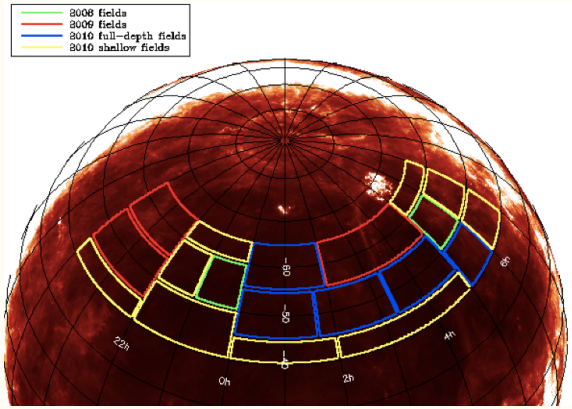
APEX-SZ

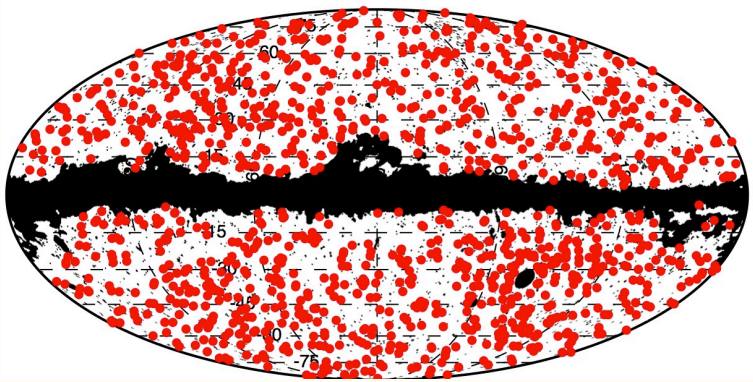
AMI

Detection of new clusters of galaxies

SZ surveys







ACT [*148*, 218, 277 GHz]

1.4' @ 148 GHz

504 deg^2 equatorial
455 deg^2 southern sky

91 SZ clusters S/N>4
- 29 new

Marriage et al. 11, Menanteau et al. 10
Hasselfield1 et al 2013;

SPT [*95, 150*, 220 GHz]

1.1' @ 150 GHz
720 deg^2
2500 deg^2 ; bright

244 SZ sources
- 178 confirmed
- 138 new

published
Staniszewski et al, 2009 (1^e SZ discovery) ;
Williamson et al. 10, Reichardt et al. 13

Planck [9 ch: 30 - 857 GHz]

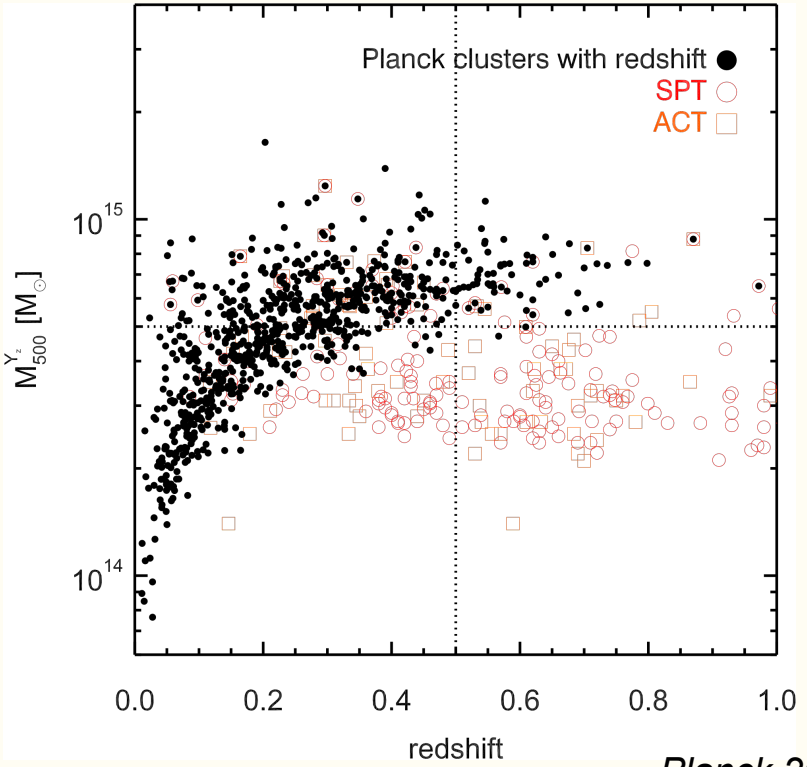
30' – 5'

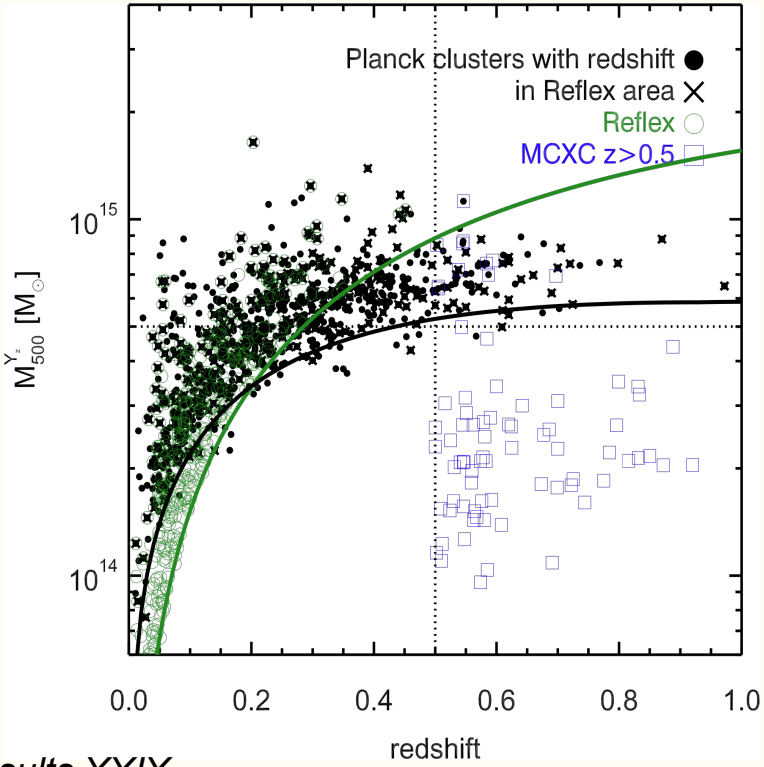
41 253 deg^2 (all-sky)

1227 SZ sources
S/N > 4.5
- 683 known
- 178 confirmed new
- 366 candidates C1-C3

Planck Early Results VIII
Planck 2013 results XXIX

Survey complementarity





Planck 2013 results XXIX

Sky coverage versus depth

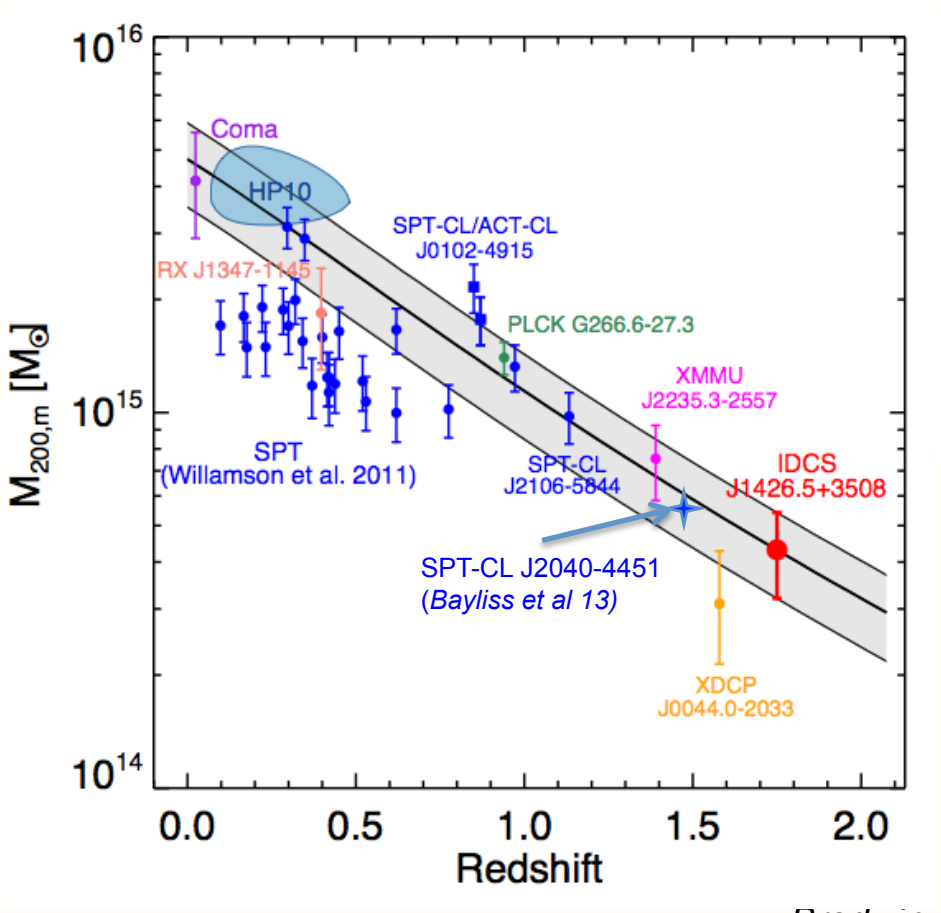
Planck: rarest high M clusters

ACT/SPT: higher z/lower M

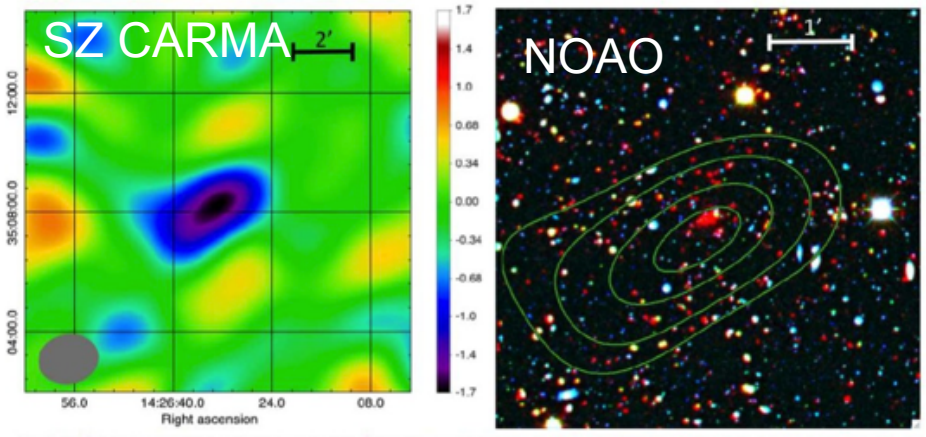
SZ: no z dimming

X-ray: (still) lower mass

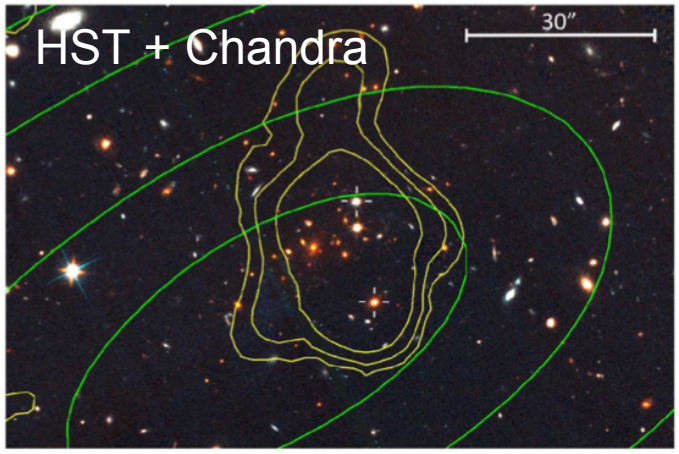
The quest of high z clusters



Brodwin et al 12



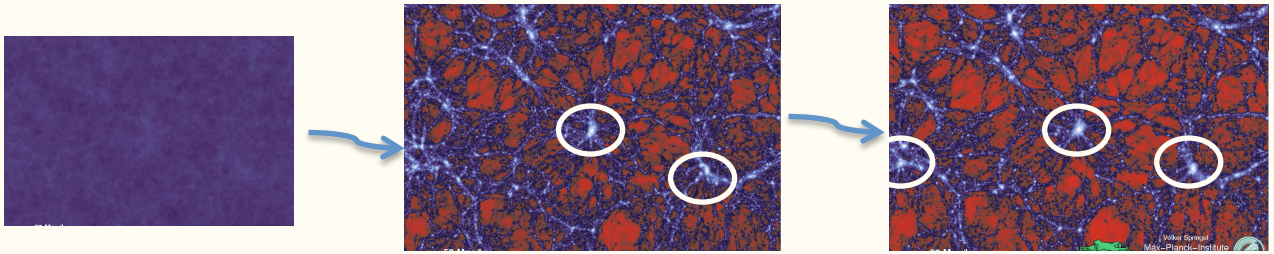
Spitzer/IRAC IDCS J1426.5+3508 z=1.75



Multi-λ synergy : SZ-X-ray-IR-Optical

Cosmology with SZ clusters

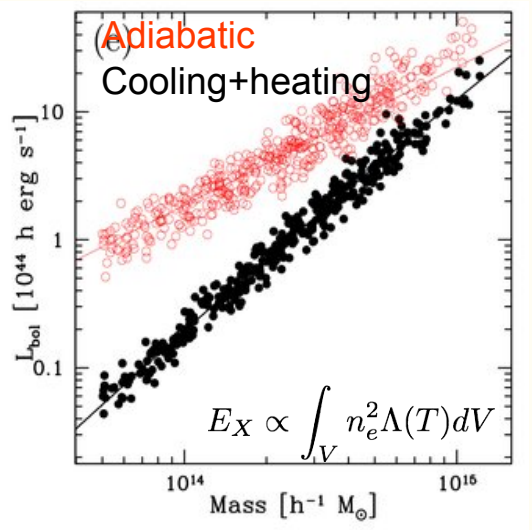
Cosmology with cluster number counts

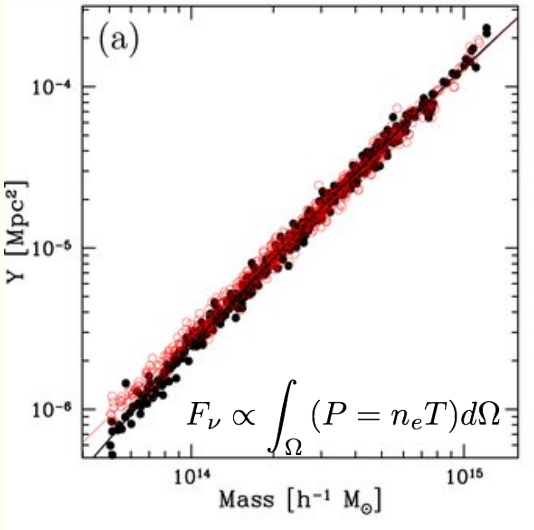


Theorie : N(M,z)

versus

σ_8 Ω_m [Ω_Λ w Ω_b n, h]





Cooling+heating

Stanek et et al, 10

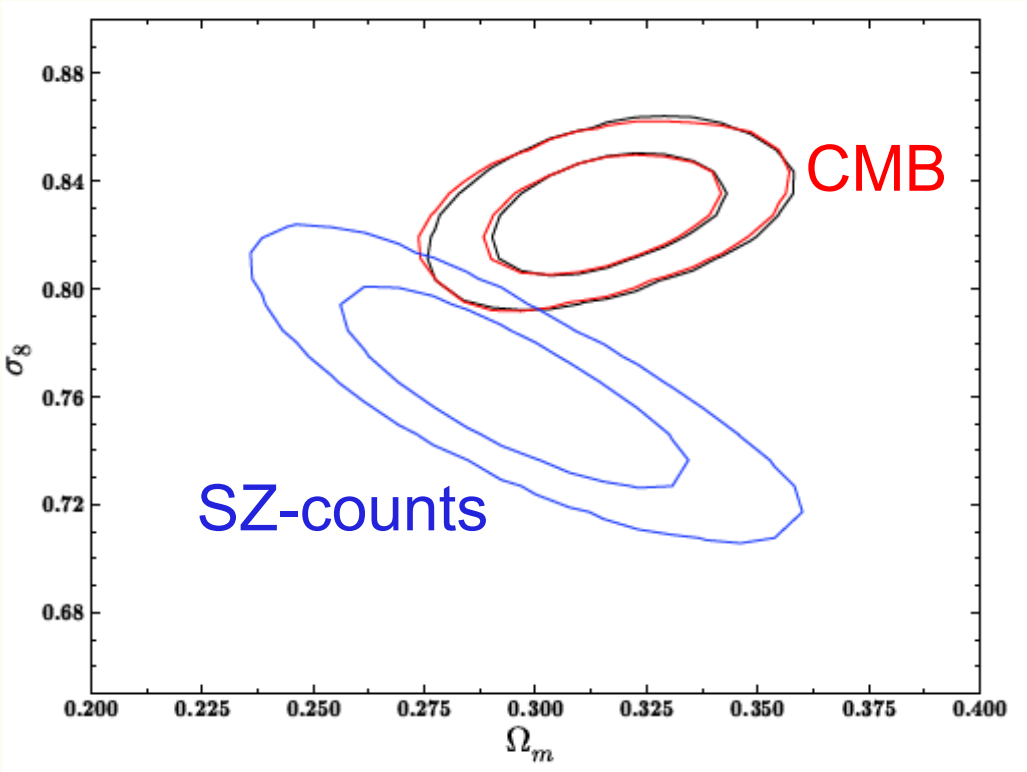
SZ (expected to be) more directly related to Mass

Y-M relation

Selection function (noise)

N(Y,z) or N(z)

SZ & CMB



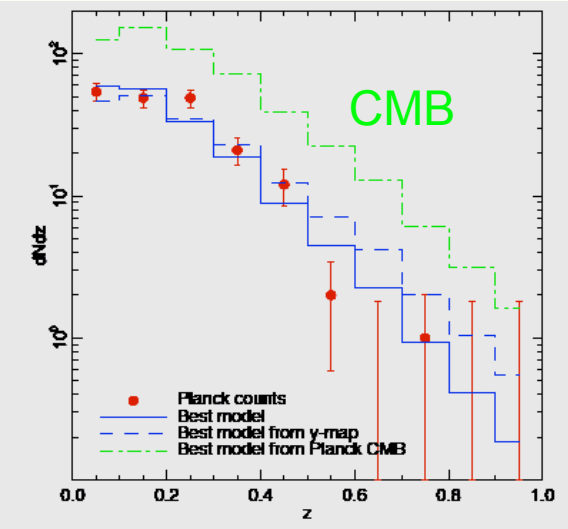
Planck 2013 results XX

From N(z)

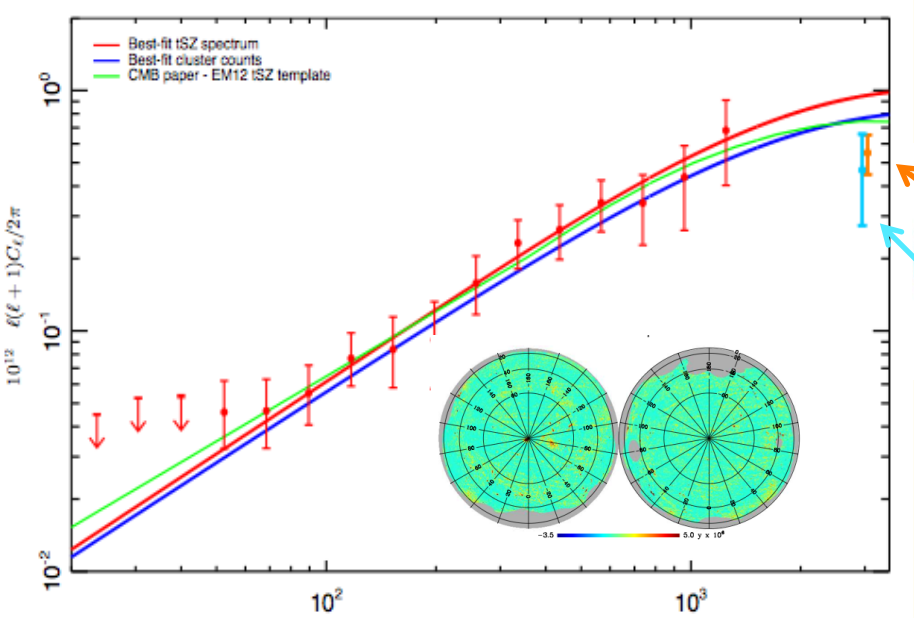
- 189 PSZ clusters
- Tinker et al mass function
- Y-M and scatter
  from Planck/XMM data
  on 71 clusters
- (1-b) ~ 0.8

~3σ discrepancy in Planck on σ_8 from SZ counts vs CMB

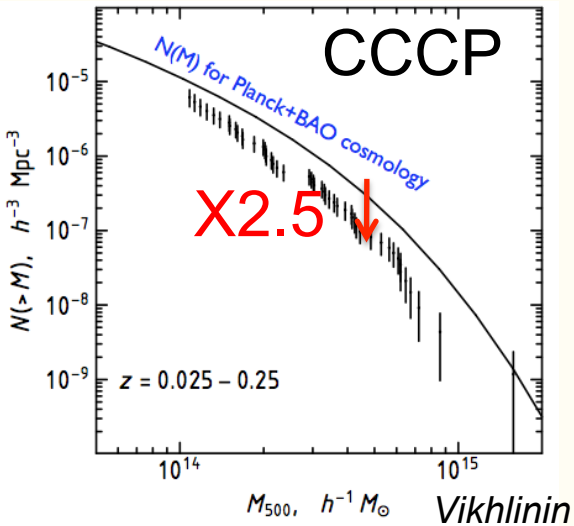
Robustness check



Planck 2013 results XX



Planck 2013 results XXI



Vikhlinin et al, 09; ESLAB13

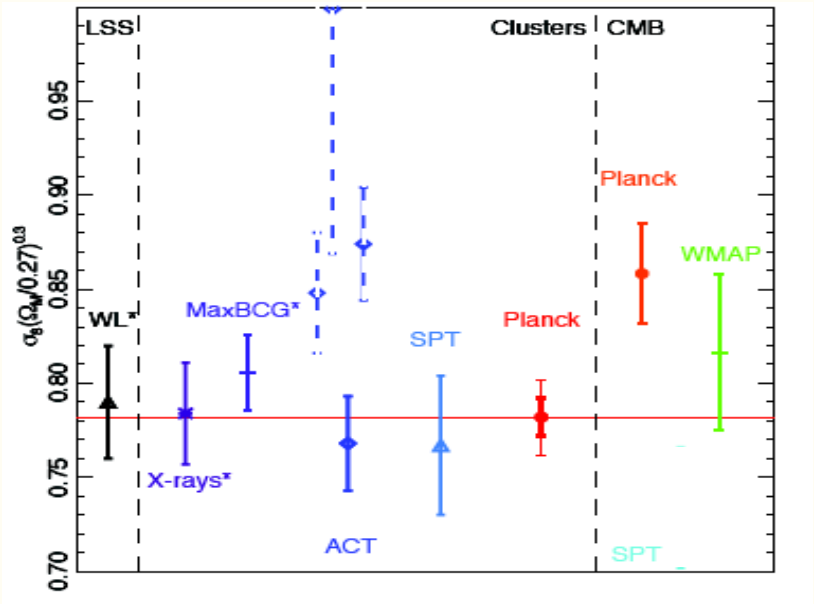
Large effect: > factor of 2 clusters “missing”

Consistency between

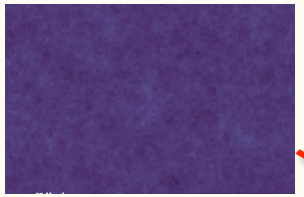
- SZ & X-ray number counts
- tSZ map power spectrum and number counts

Comparison with other constraints

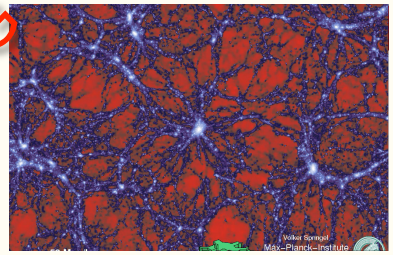
Experiment	CPPP[a]	MaxBCG[b]	ACT[c]	SPT	*Planck* SZ
Reference	Vikhlinin et al.	Rozo et al.	Hasselfield et al.	Reichardt et al.	This work
Number of clusters	49+37	70810	15	100	189
Redshift range	[0.025,0.25] and [0.35,0.9]	[0.1,0.3]	[0.2,1.5]	[0.3,1.35]	[0.0,0.99]
Median mass ($10^{14}h^{-1}M_{sol}$)	2.5	1.5	3.2	3.3	6.0
Probe	$N(z, M)$	$N(M)$	$N(z, M)$	$N(z, Y_X)$	$N(z)$
S/N cut	5	($N_{200} > 11$)	5	5	7
Scaling	Y_X–T_X, M_{gas}	N_{200}–M_{200}	several	L_X–M, Y_X	Y_{SZ}–Y_X
$\sigma_8(\Omega_m/0.27)^{0.3}$	0.784 ± 0.027	0.806 ± 0.033	0.768 ± 0.025	0.767 ± 0.037	0.782 ± 0.010

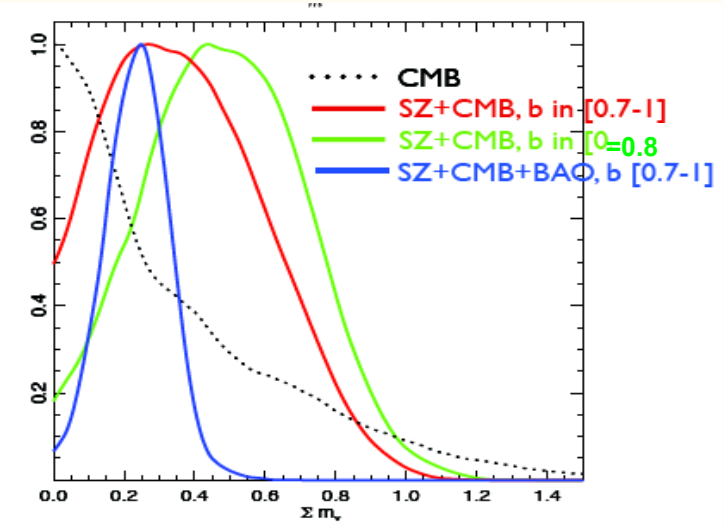


Reconciling SZ-counts & CMB?

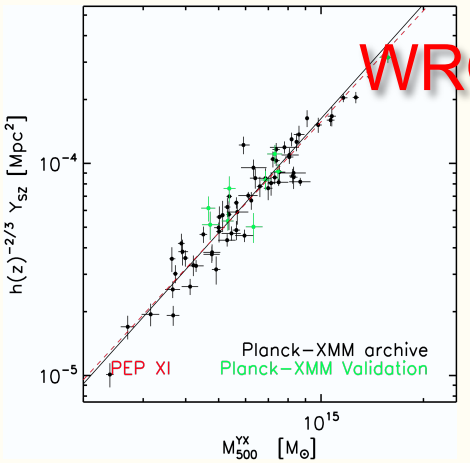


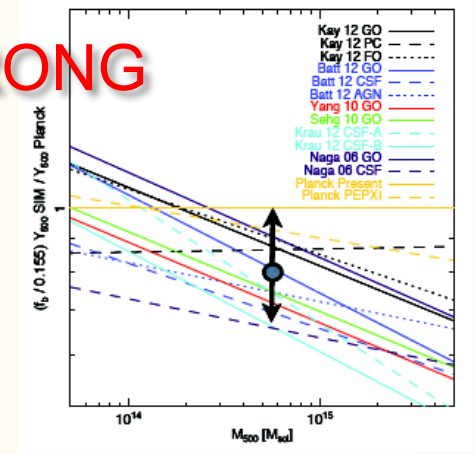
WRONG





WRONG





- Missing ~half of massive clusters **NO**
- (1-b) = 0.55 instead of 0.8
  true M higher by ~50% unlikely
- Σm_ν ~0.2 ev possible
- combination (m_ν >0 high b_{HE} X-ray calibration)

More from CMB lensing polarisation measurements
+ follow-up for mass calibration

Statistical properties of Cluster population

X-ray prediction versus SZ data

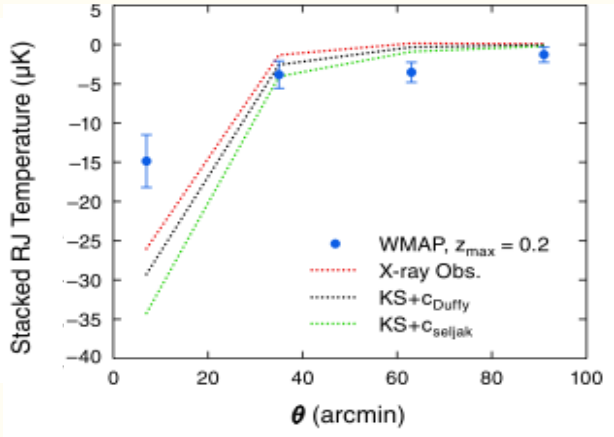
ACCEPTED FOR PUBLICATION IN THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES
Preprint typeset using LaTeX style emulateapj v. 11/10/09

SEVEN-YEAR WILKINSON MICROWAVE ANISOTROPY PROBE (*WMAP*[1]) OBSERVATIONS: COSMOLOGICAL INTERPRETATION

E. KOMATSU[2], K. M. SMITH[3], J. DUNKLEY[4], C. L. BENNETT[5], B. GOLD[5], G. HINSHAW[6], N. JAROSIK[7], D. LARSON[5], M. NOLTA[8], L. PAGE[7], D. N. SPERGEL[3,9], M. HALPERN[10], R. S. HILL[11], A. KOGUT[6], M. LIMON[12], S. S. MEYER[13], N. ODEGARD[11], G. S. TUCKER[14], J. L. WEILAND[11], E. WOLLACK[6], AND E. L. WRIGHT[15]

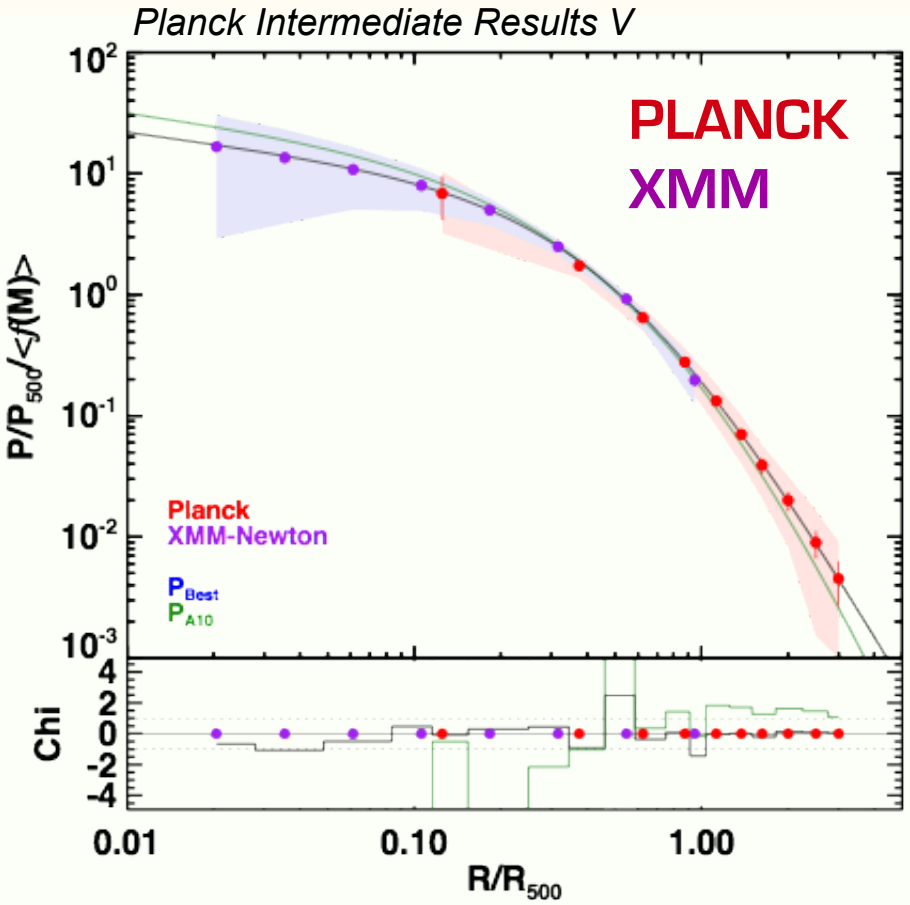
Accepted for Publication in the Astrophysical Journal Supplement Series

Zel'dovich (SZ) effect at the locations of known clusters of galaxies. The measured SZ signal agrees well with the expected signal from the X-ray data on a cluster-by-cluster basis. However, it is a factor of 0.5 to 0.7 times the predictions from "universal profile" of Arnaud et al., analytical models, and hydrodynamical simulations. We find, for the first time in the SZ effect, a significant difference between the cooling-flow and non-cooling-flow clusters (or relaxed and non-relaxed clusters), which can explain some of the discrepancy. This lower amplitude is consistent with the lower-than-theoretically-expected SZ power spectrum recently measured by the South Pole Telescope collaboration.



missing hot baryons ?

X-ray & SZ Pressure profile



- 62 ESZ clusters with XMM archive data

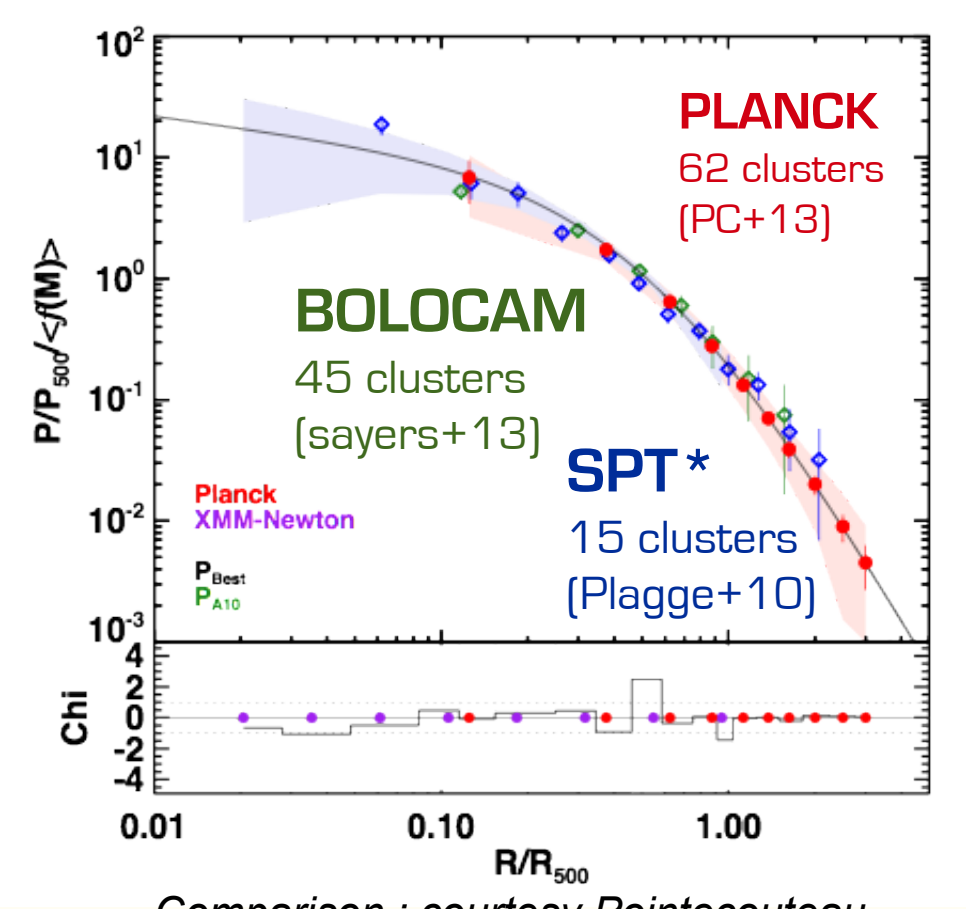
$$F_\nu \propto \int_\Omega (P = n_e T) d\Omega$$

- Deprojection/deconvolution of profile from Planck SZ map

⇒ 0.02-5 R_{500} from X-ray+SZ

X-ray and SZ view consistent , No 'missing' hot baryons

SZ Pressure profiles



Comparison : courtesy Pointecouteau

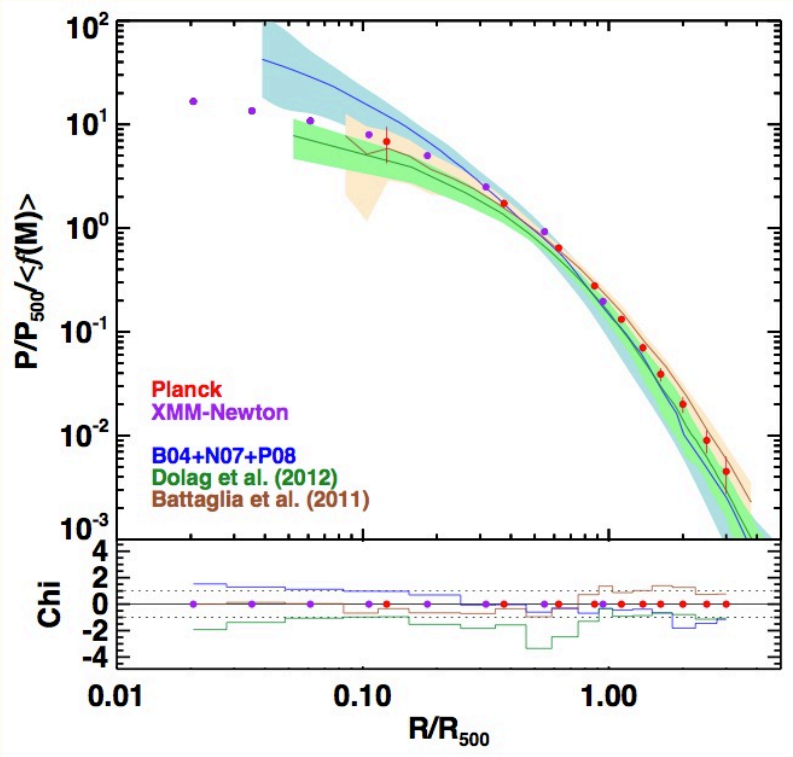
* arbitrarly rescaled

See also

Aslanbeigi et al, 13 WMAP
Bonamente et al 12 (SZA+Chandra)

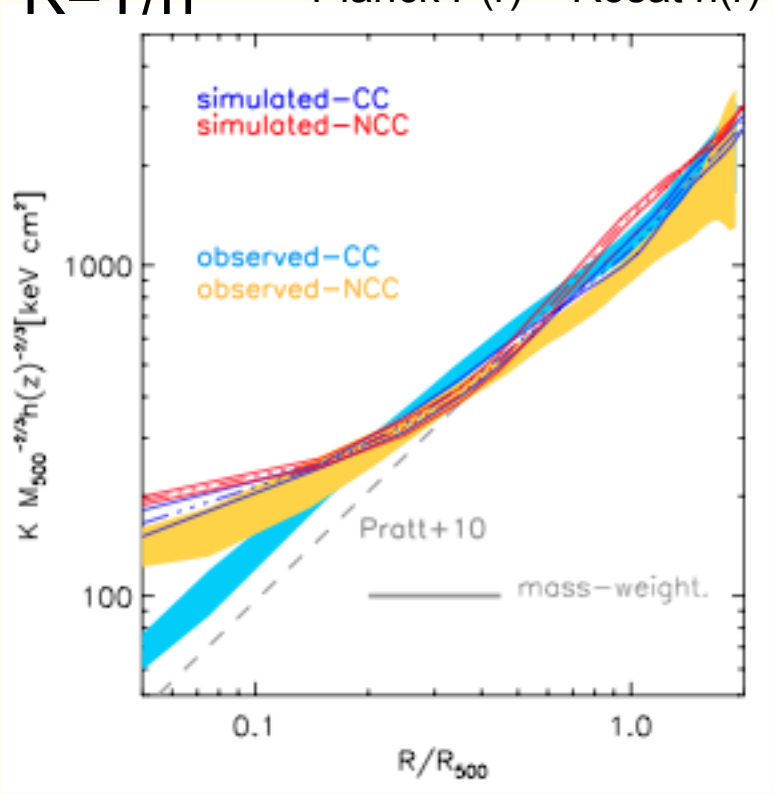
Excellent agreement between measurements

Comparison with numerical simulations



Planck Intermediate Results V

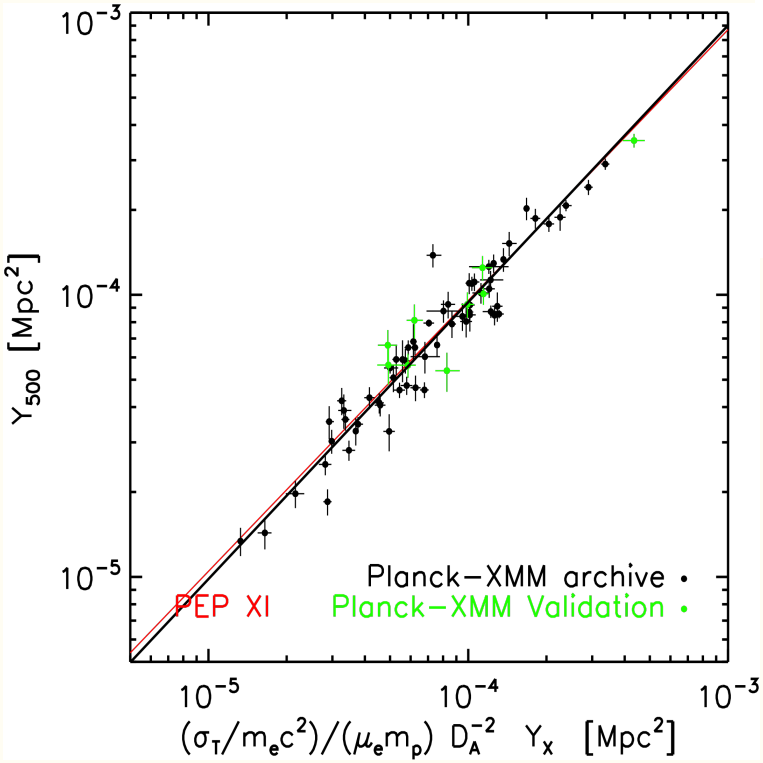
$K=T/n^{2/3}$ Planck P(r) + Rosat n(r)



Eckert et al, 2013

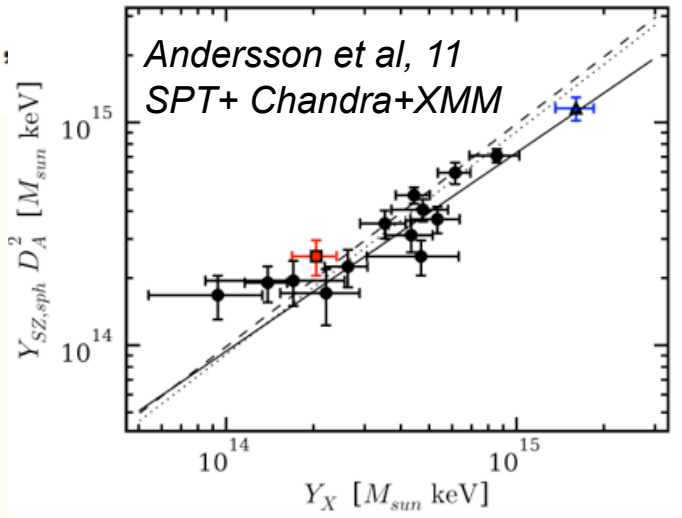
Probing outskirt physics

SZ-X scaling relation



$$\frac{D_A^2\, Y_{500}}{C_{XSZ}\, Y_X} = \frac{1}{Q}\frac{\langle n_e T\rangle_{R500}}{\langle n_e\rangle_{R500} T_X}$$

$$Q = \frac{\sqrt{\langle n_e^2\rangle_{dr}}}{\langle n_e\rangle_{dr}}$$

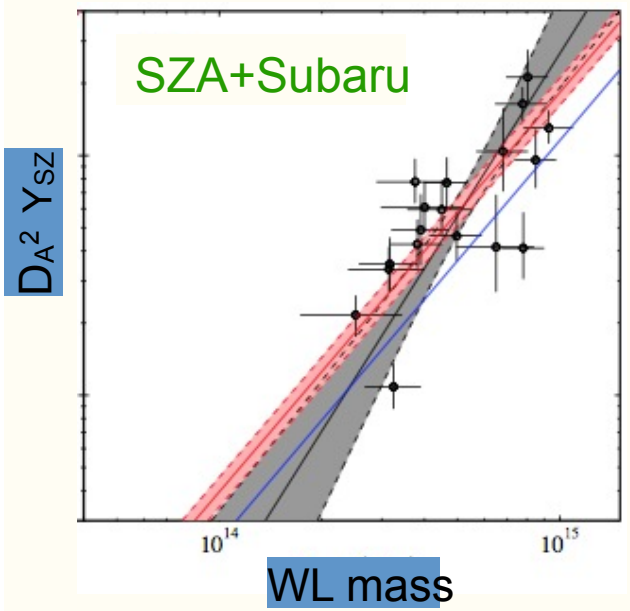


$$Y_X = M_{gas} T_X$$

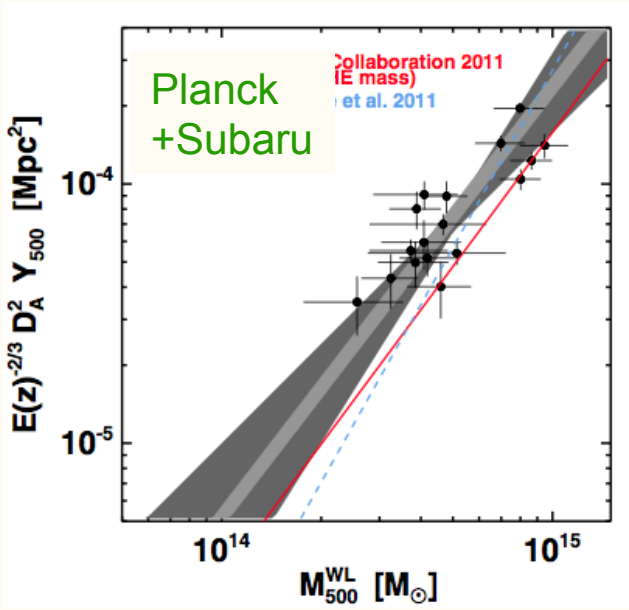
- Ratio consistent with X-ray P shape
- Limit on clumpiness
- Error dominated by systematics
- Low scatter relation
  - ⇔ Y_{SZ}/Y_X good mass proxy

Planck 2013 results XXIX
Update of Planck Early Results XI,IX +Planck Intermediate Results I,IV
See also, Rozo, Vikhlinin & More, 2012 (Planck + Chandra)

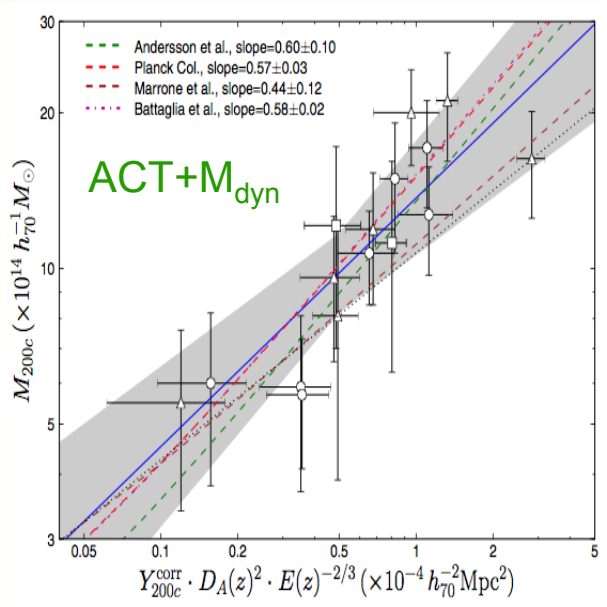
Weighting clusters and Observable-Mass relation



Marrone et al, 11



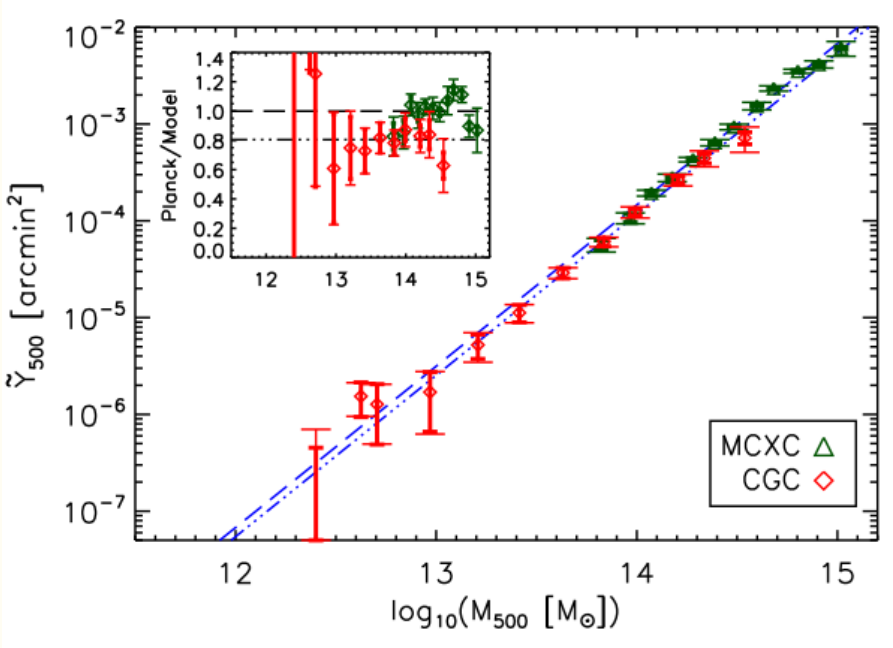
Planck intermediate Results III, 13



Sifon et al, 13

General agreement within errors
Systematics on M-Y ~ 20%

Going to low halo masses



Planck intermediate Results XI, 13

Stacking around SDSS LBGs

Lopt-M (simul) & M-Y

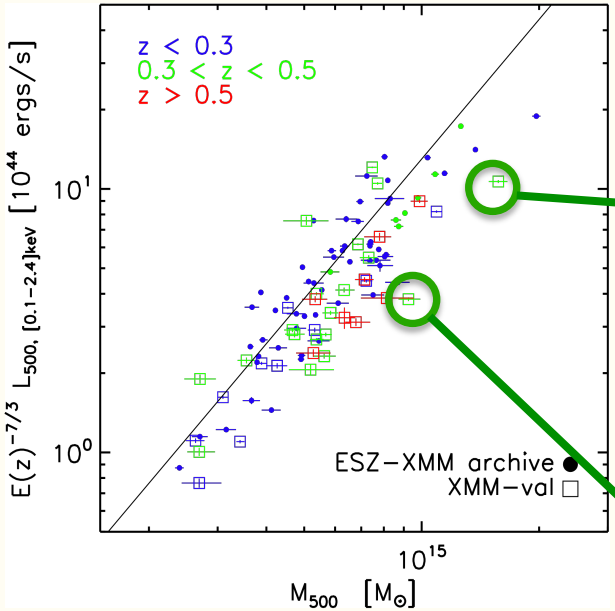
=> Hot halo gas down to $10^{12}M_o$

But still Y for optical selected clusters not understood

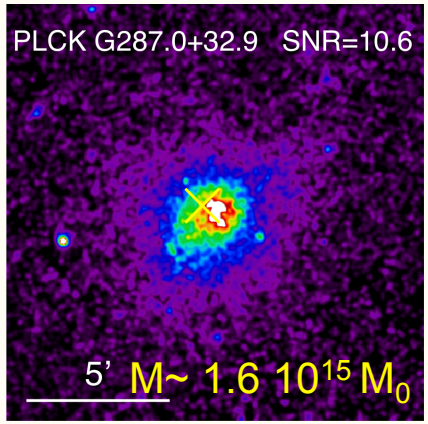
Planck Early Results XII, Sehgal 12,

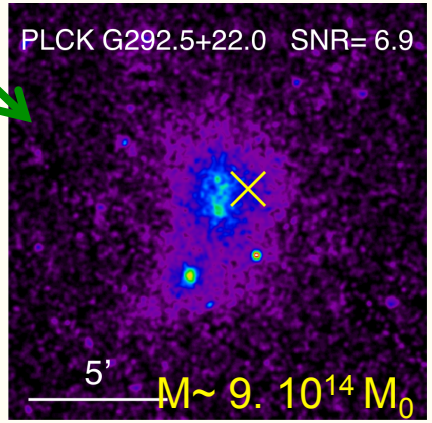
More on cluster physics

X-ray versus SZ selection



Planck Intermediate Results IV



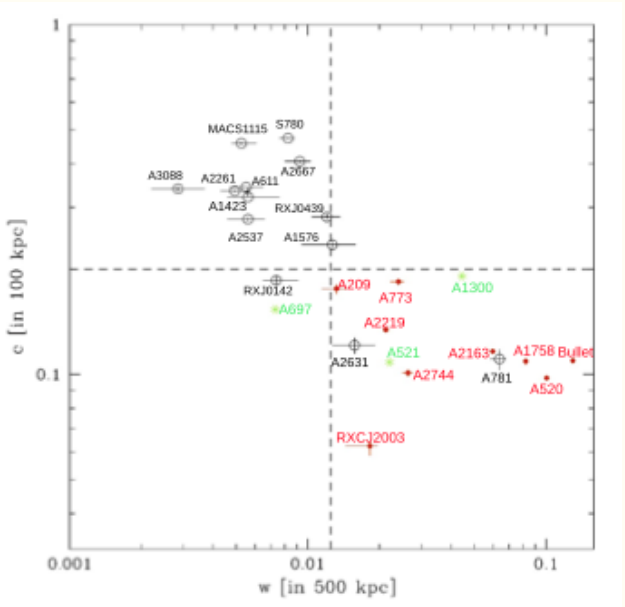


Larger $M–L_X$ dispersion and smaller normalisation than thought?

Dynamically perturbed clusters under-represented at limit of X-ray surveys ?

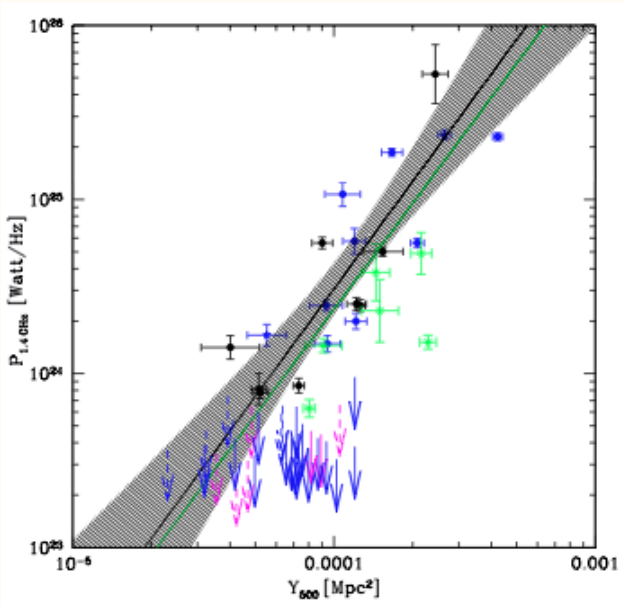
The radio halo – merger connection

Cassano et al 13



Departure from equilibrium

GMRT + ESZ Planck

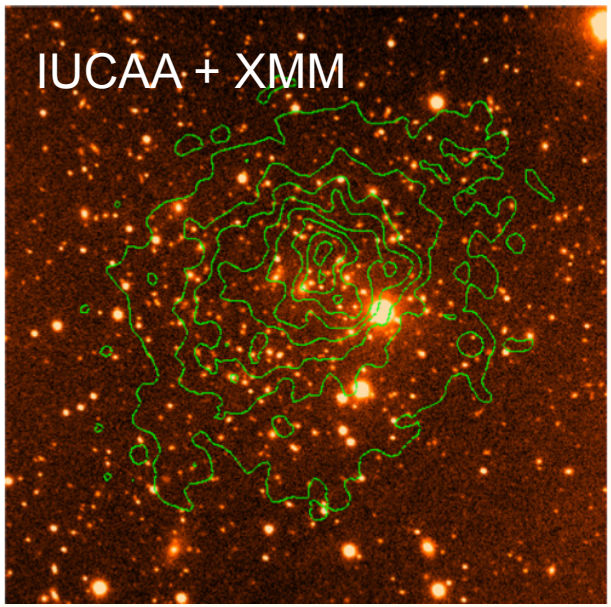


Still bimodality

But lower radio quiet fraction (20%) than in X-ray selected sample (65%)

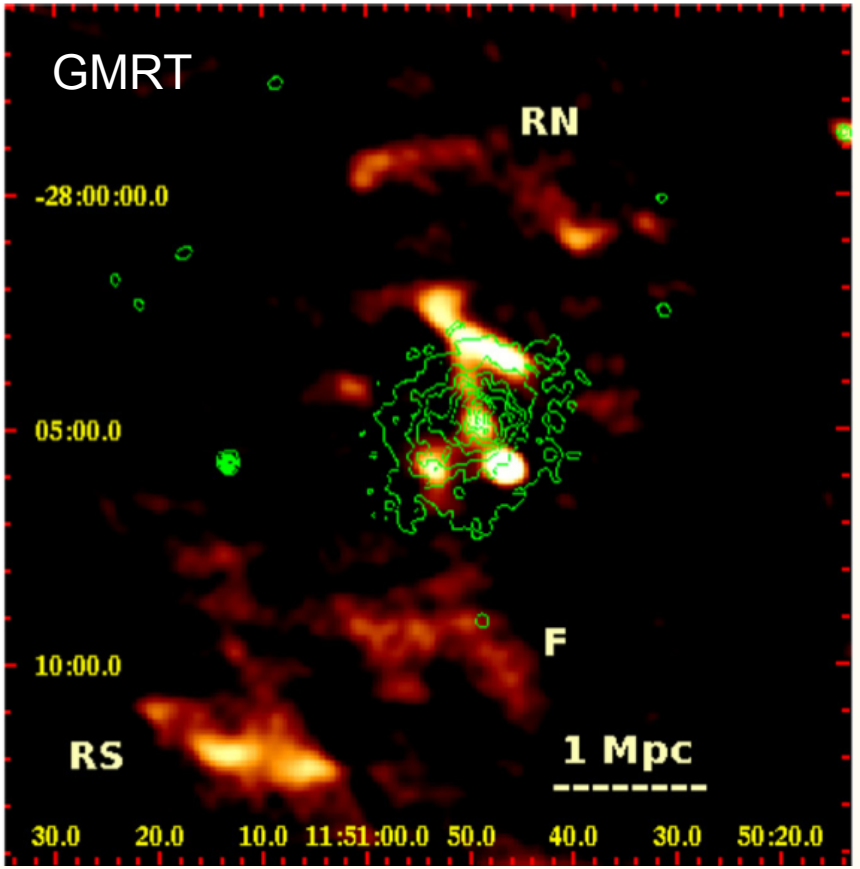
from Sommer & Basu, 13

A new merging galaxy cluster found with Planck/XMM/GMRT



Bagchi et al., 2011

PLCK G287.0+32.9 z=0.39 kT ~13 keV



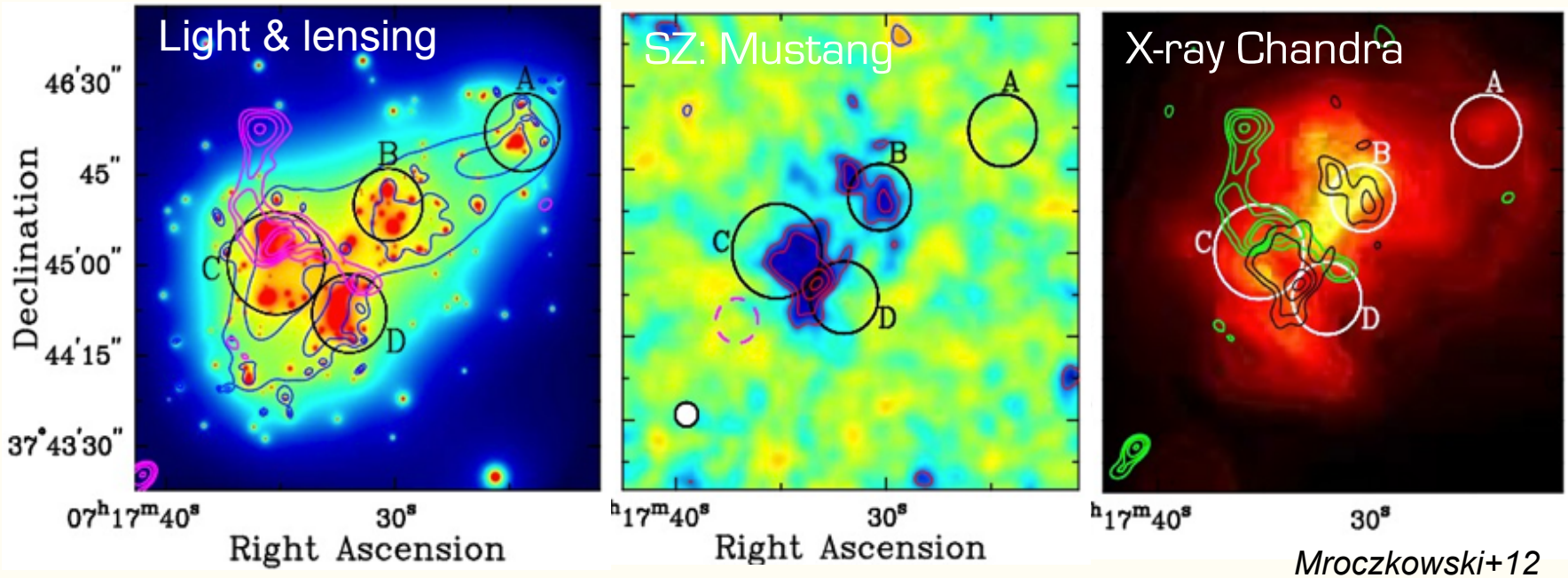
Giant relics

Key to understand merger physics and non thermal phenomena

See also PLCK- ESZ G241.97+14.85 ; *van Weeren et al, 2013*
PLCK- ESZ G171.9−40.7; radio halo *Giantucci et al, 2013*

A multi-λ view of a cluster

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

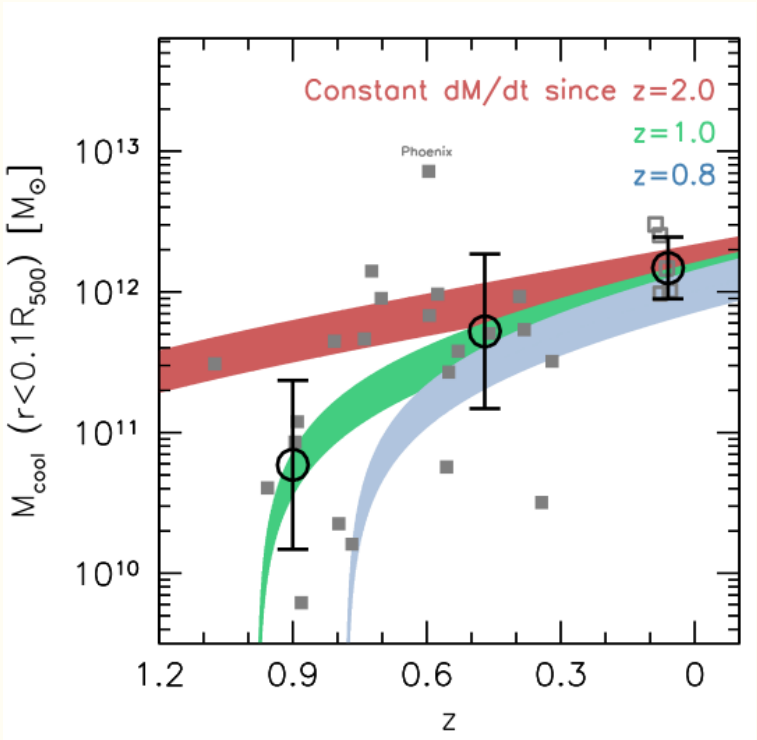


Mroczkowski+12

MACS J0717.5+3745 z= 0.54

Shock heated gas in a complex triple merger system

Complete follow-up of SZ samples



McDonald et al, 13

Chandra XVP on SPT sample
83 clusters 0.3<z<1.2

Steady growing of cool core

Conclusion

- Remarquable progress in SZ cluster detection
  - from first SZ discovery in 2009 to > 1000 clusters sample from Planck/SPT/ACT
  - provide unique high z, high M, close to mass selected sample
- Cluster cosmology
  - Excellent agreement between cluster constrains
  - Interesting Cluster-CMB 3 σ discrepancy to be understood

    => mass estimate (cluster physics), ν mass (particle physics), others?
- Probe of cluster formation and evolution from combined SZ-other λ studies
  - consistent X-ray and SZ view of the ICM
  - New probe of outskirt; constrains on clumpiness & T equipartition
  - A more disturbed population than thought from X-ray selected sample
  - New insight on merger physics from radio/X-ray/high resolution SZ/lensing
- Prospects: much more on cosmology and cluster formation
  - larger sample from Planck full mission, ACTpol, SPTpol
  - cross correlation between SZ (eg Planck) and radio (eg LOFAR) survey
  - On going Chandra/XMM/ESO etc. follow-up of complete SZ samples