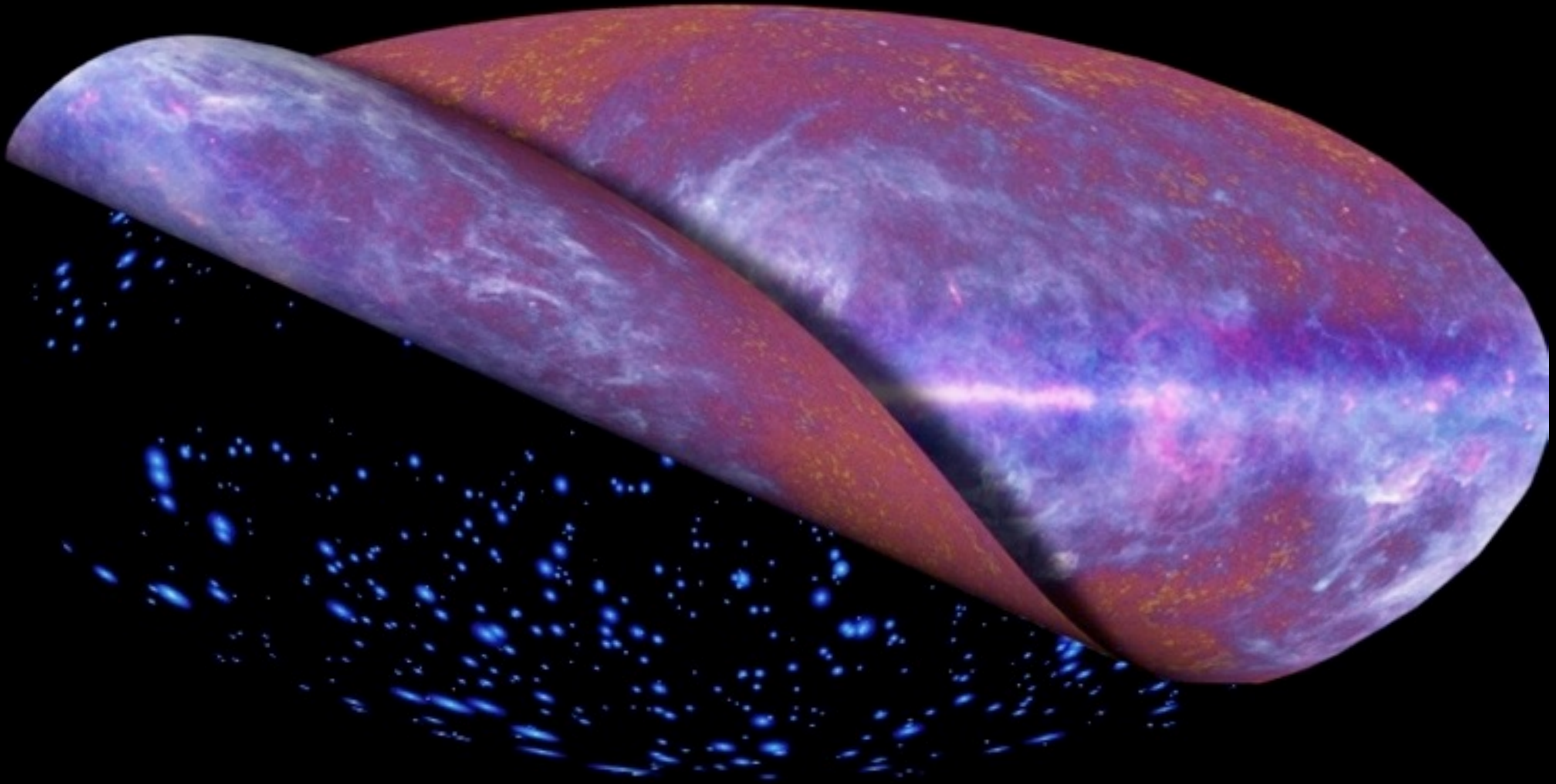


Planck unveils the Sunyaev-Zeldovich effect

planck

Cosmology with the Planck thermal Sunyaev-Zeldovich effect map

Based on Planck 2015 results: XXII, XXIV, XXVII

J.F. Macías-Pérez

LPSC Grenoble

on behalf of the ***Planck Collaboration***

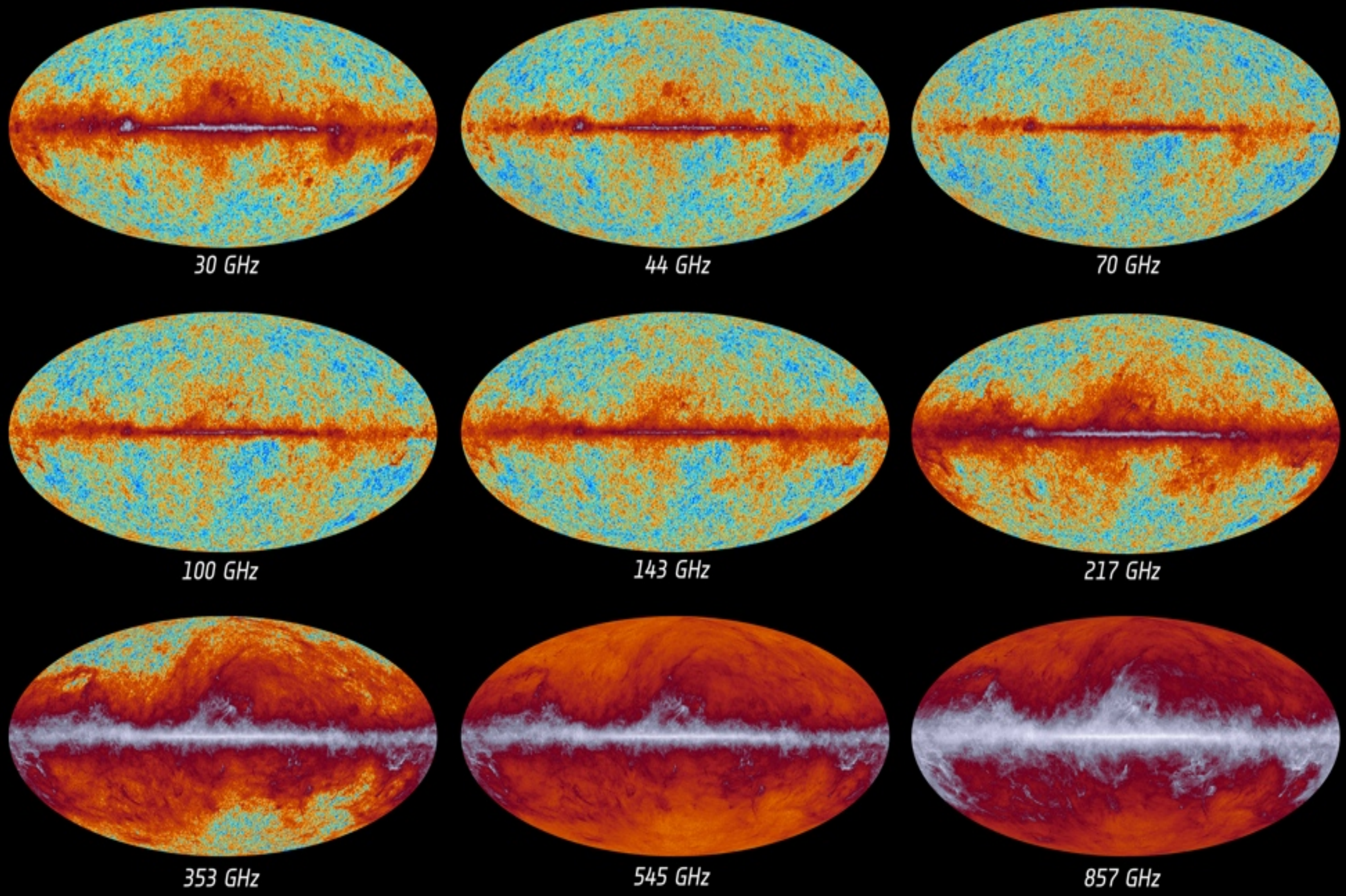
LPSC Grenoble

Outline

planck

- y-map reconstruction and characterisation
- cluster physics for cosmology
- cosmology with the y-map
  - -power spectrum
  - -higher order statistics

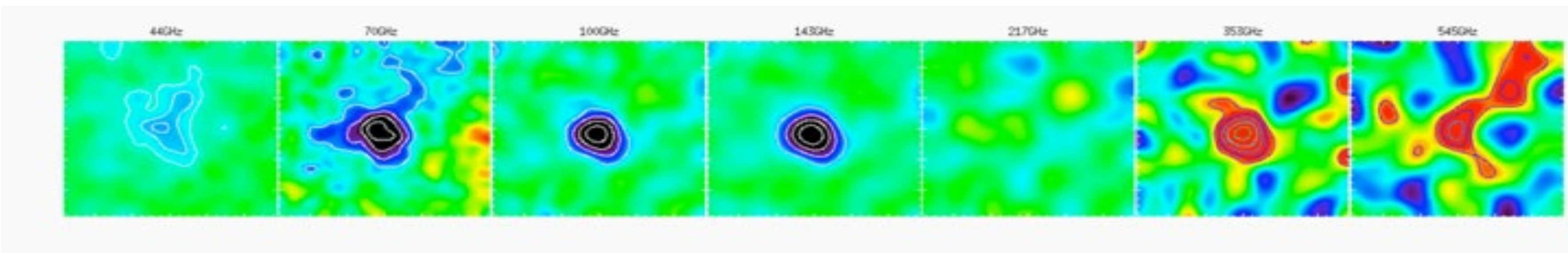
Planck sky maps



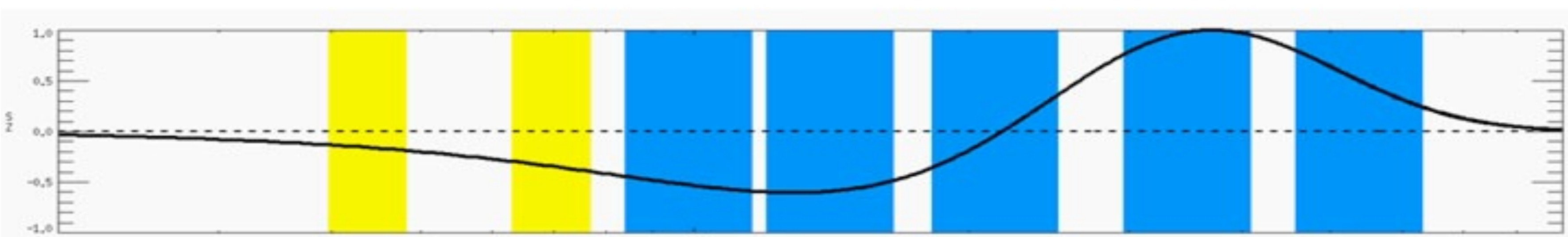
Mapping tSZ effect with Planck

-Inverse Compton between CMB photons and free hot electrons on clusters of galaxies

$$\frac{\Delta T_{TSZ}}{T_{CMB}} = f(x)y = f(x)\int n_e \frac{K_B T_e}{m_e c^2}\sigma_T d\ell \qquad f(x) = \left(x\frac{e^x+1}{e_x-1} - 4\right)$$



A2319



-The Planck satellite has been designed to map the tSZ signal

From Planck channel maps to a y-map

-Adapted component separation algorithms as in Planck 2013 results XXI:

NILC and MILCA

[Remazeilles et al 2011/2012; Hurier et al 2010/2012]

➡ constraints on electromagnetic spectra: preserve tSZ effect and remove CMB

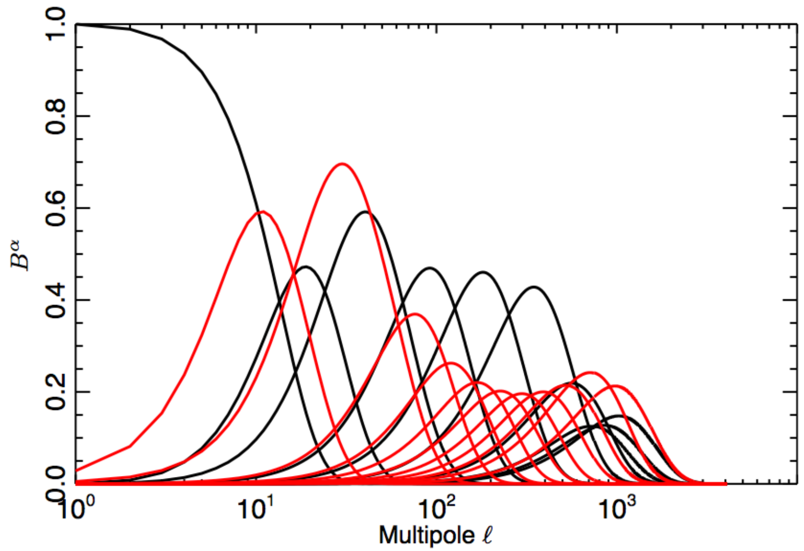
➡ simultaneous spatial (pixel domain) and spectral (multipole domain) localisation - updated

- Use full mission HFI channels from 100 to 857 GHz

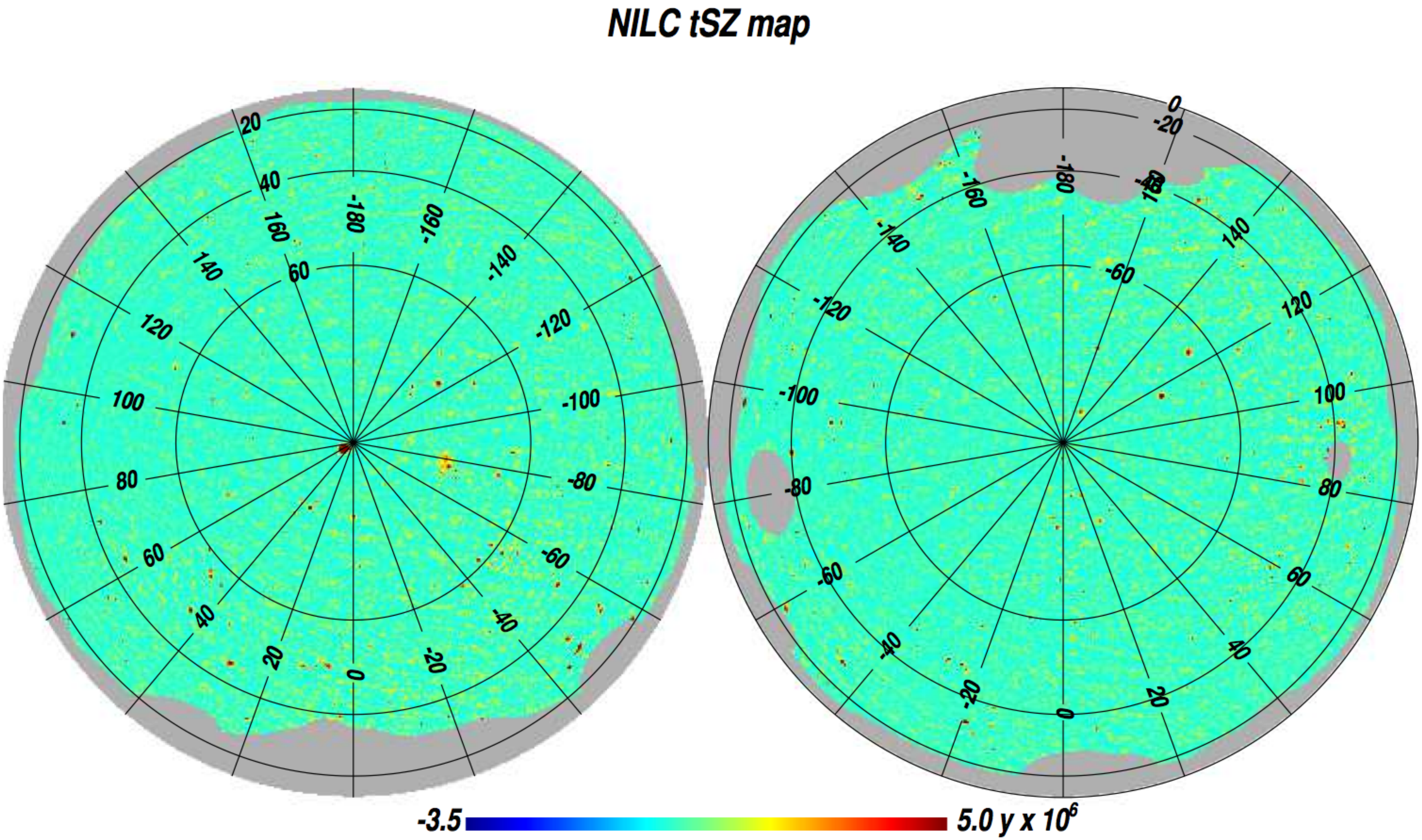
➡ 857 GHz used only for ell < 300

- Common resolution of 10 arcmin

-Validation on simulations



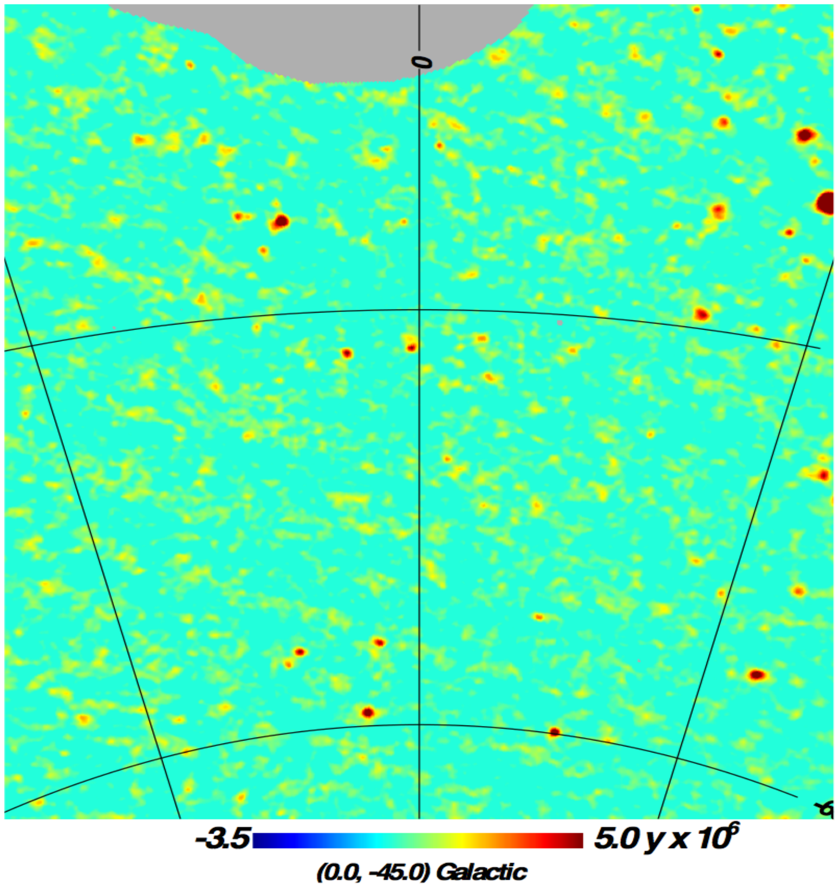
Planck Compton parameter map (y-map)



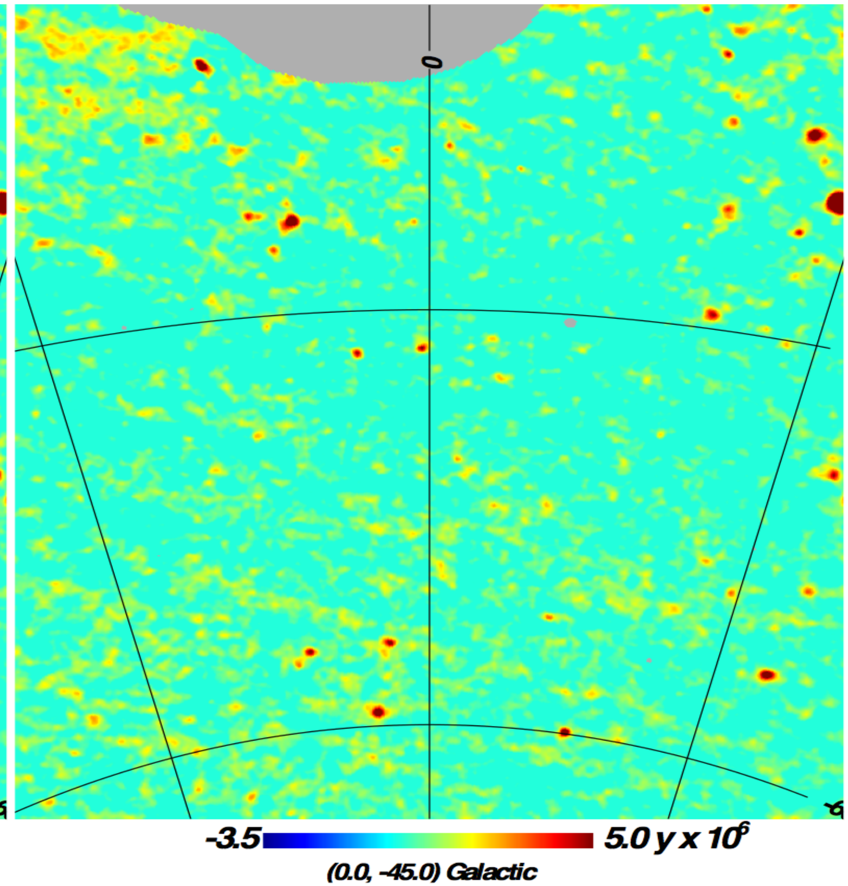
Planck Compton parameter map II

Go to page 23

NLC tSZ map



MILCA tSZ map

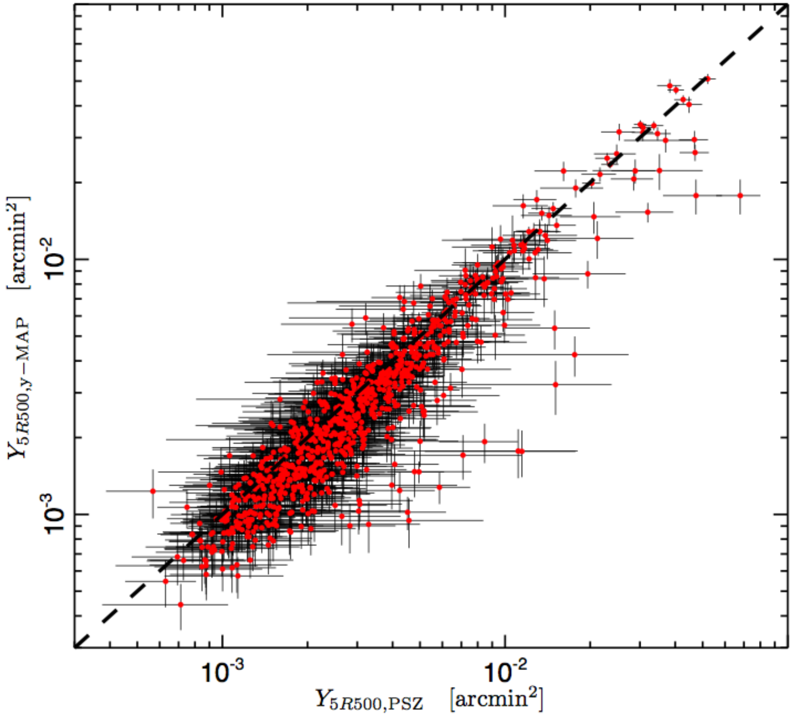


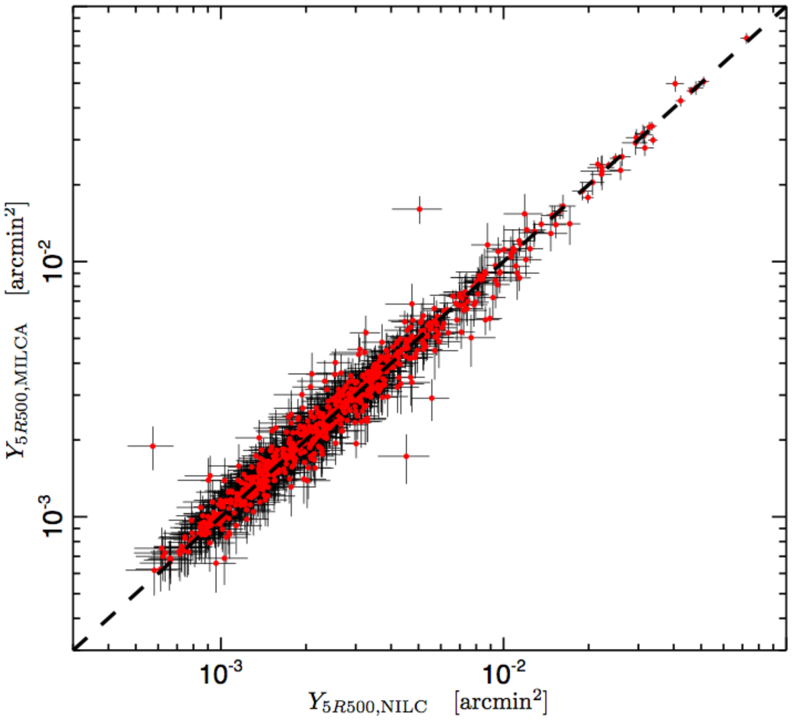
- Known astrophysical point sources (mainly radio and IR) have been masked out
- For radio sources (negative in the y-maps) blind detection has been used to confirm and extend the mask

Planck y-map: cluster and point sources

Use two independent methods to blindly search for clusters on the y-map:

- Single frequency matched filter (MF) [Melin et al 2006]
- IFCAMEX (MHW filtering) [Lopez-Caniego et al 2006]





➡ number of detected clusters and measured flux consistent with Planck SZ2 catalogue

Outline

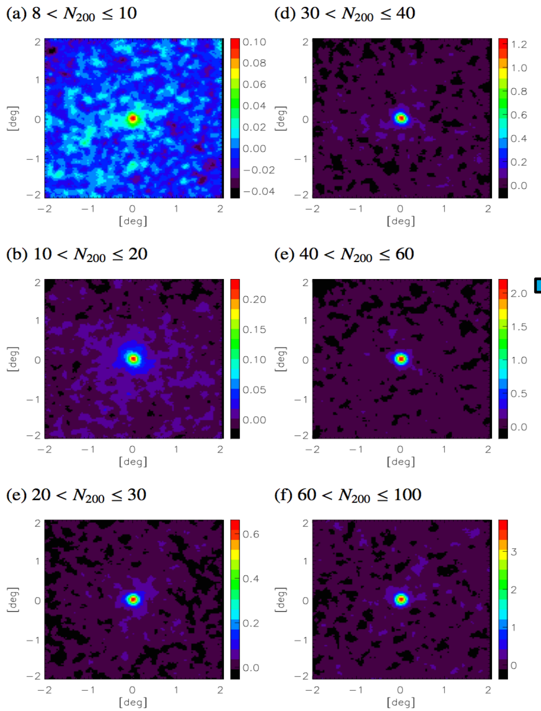
- y-map reconstruction and characterisation
- cluster physics for cosmology
  - power spectrum
  - higher order statistics

A bit of scaling relations

-SDSS III catalogue of 132684 clusters of galaxies [Wen et al 2012]

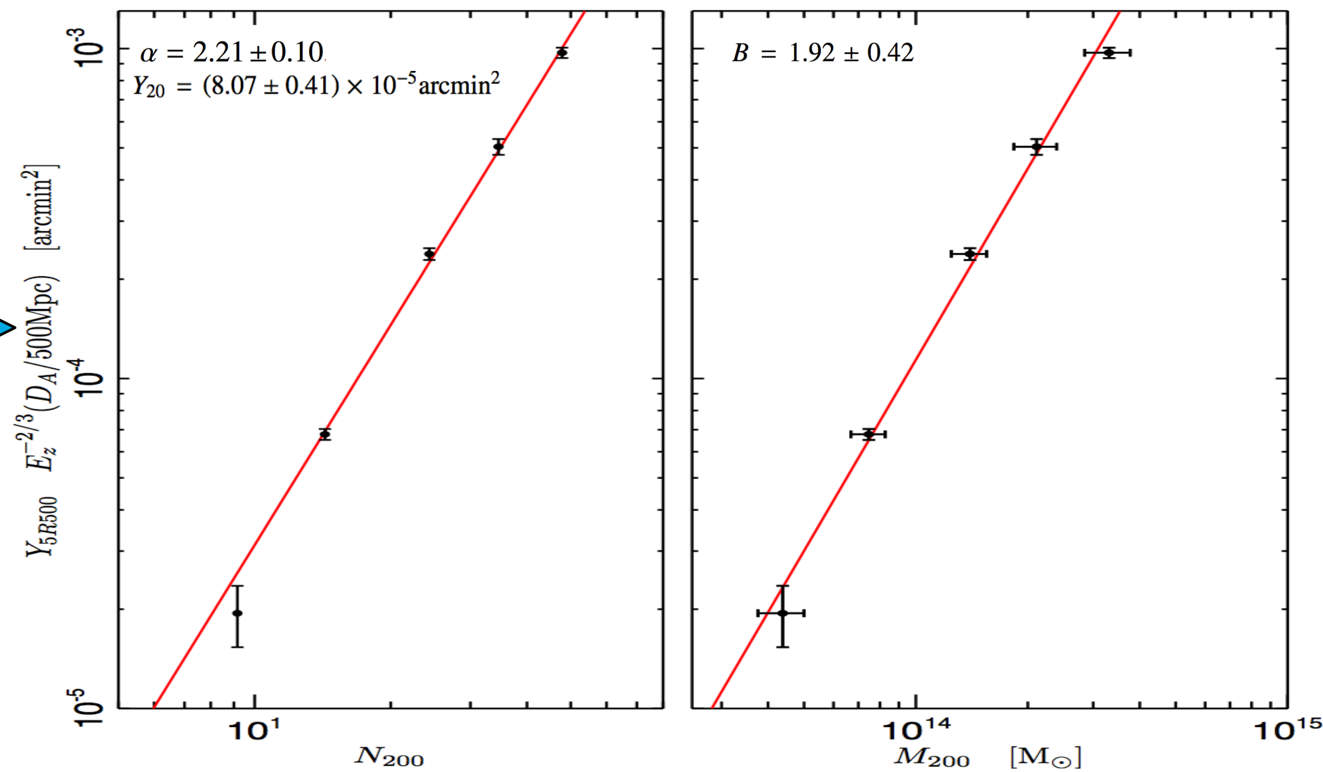
-stack unresolved groups and clusters with $N_{200} < 100$ at $z < 0.45$ for which SNR < 1 in the y-map

- about 20000 objects per bin



$$Y_{5r_{500}} E_z^{-2/3} \left(\frac{D_A(z)}{500\,Mpc} \right)^2 = Y_{20} \left(\frac{N_{200}}{20} \right)^{\alpha}$$

$$Y_{5r_{500}} E_z^{-2/3} \left(\frac{D_A(z)}{500\mathrm{Mpc}} \right)^2 = Y_0 \left(M_{200} \right)^{B}$$

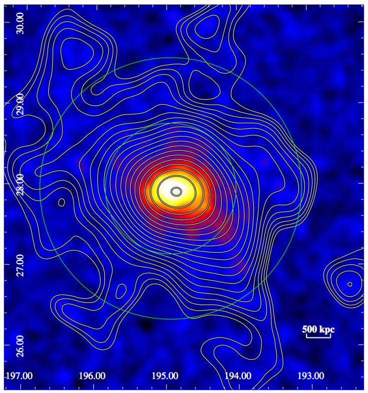


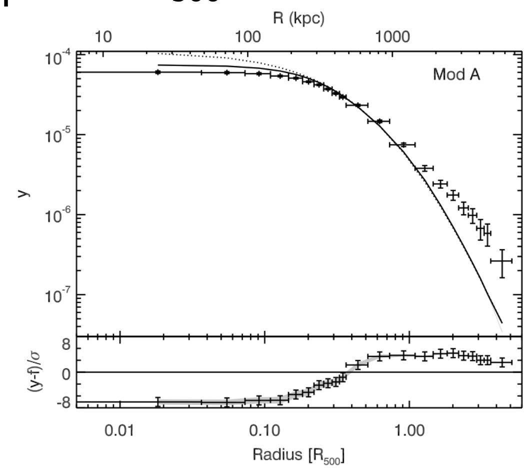
- ✓ Find compatible results with Planck intermediate papers [Planck collaboration 2011]
- ✓ Using N_{200}-M_{200} results from [Covone et al 2014] we extend the analysis to Y_{5R500} - M_{200}
  - results compatible with self-similar expectation

Measuring pressure profiles

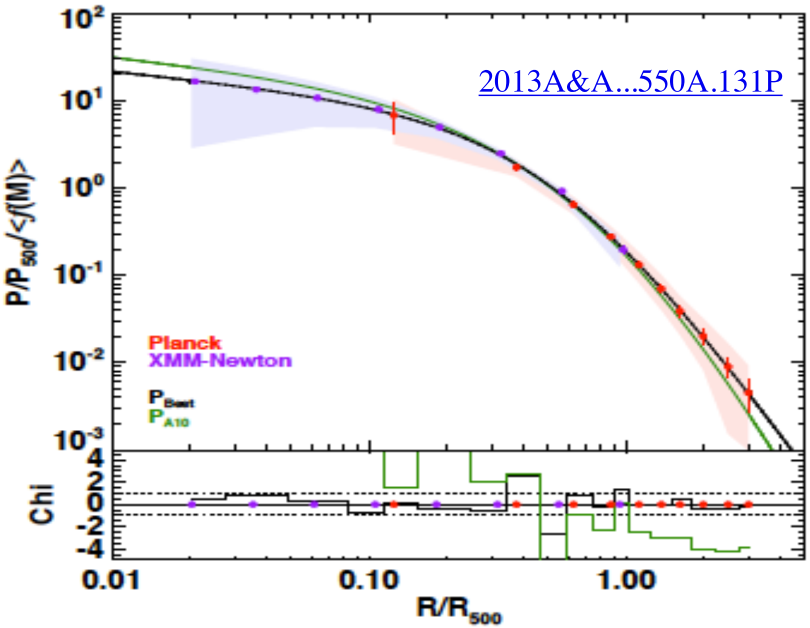
Planck 2013 release

❖ Nearby clusters: up to $3 \times R_{500}$ for COMA



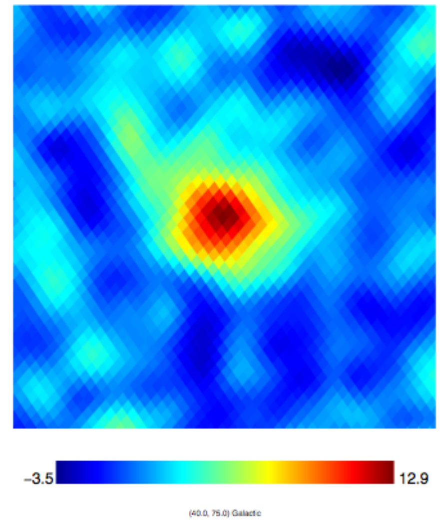


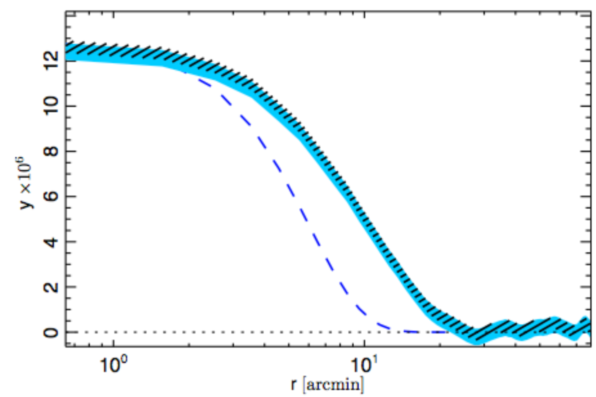
❖ Statistical analysis in 62 nearby massive clusters



Planck 2015 results

❖ Radial profiles for low SNR (>5) clusters



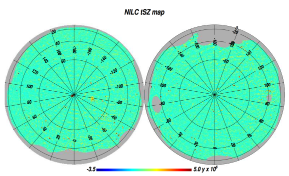


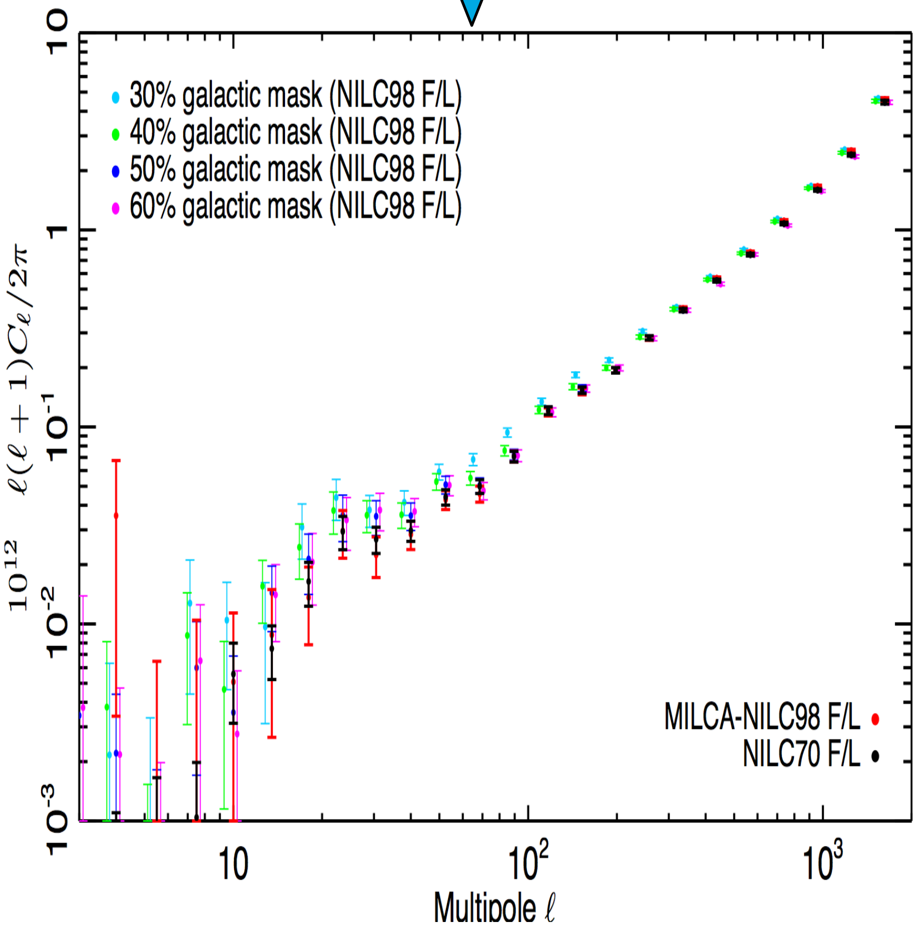
JF. Macias-Perez
on behalf of the **Planck**

Outline

- y-map reconstruction and characterisation
- cluster physics for cosmology
- cosmology with the y-map
  - angular power spectrum
  - higher order statistics

Power spectrum analysis I : foregrounds





- Compute cross-power spectrum of the FIRST and LAST maps

[Tristram et al 2005]

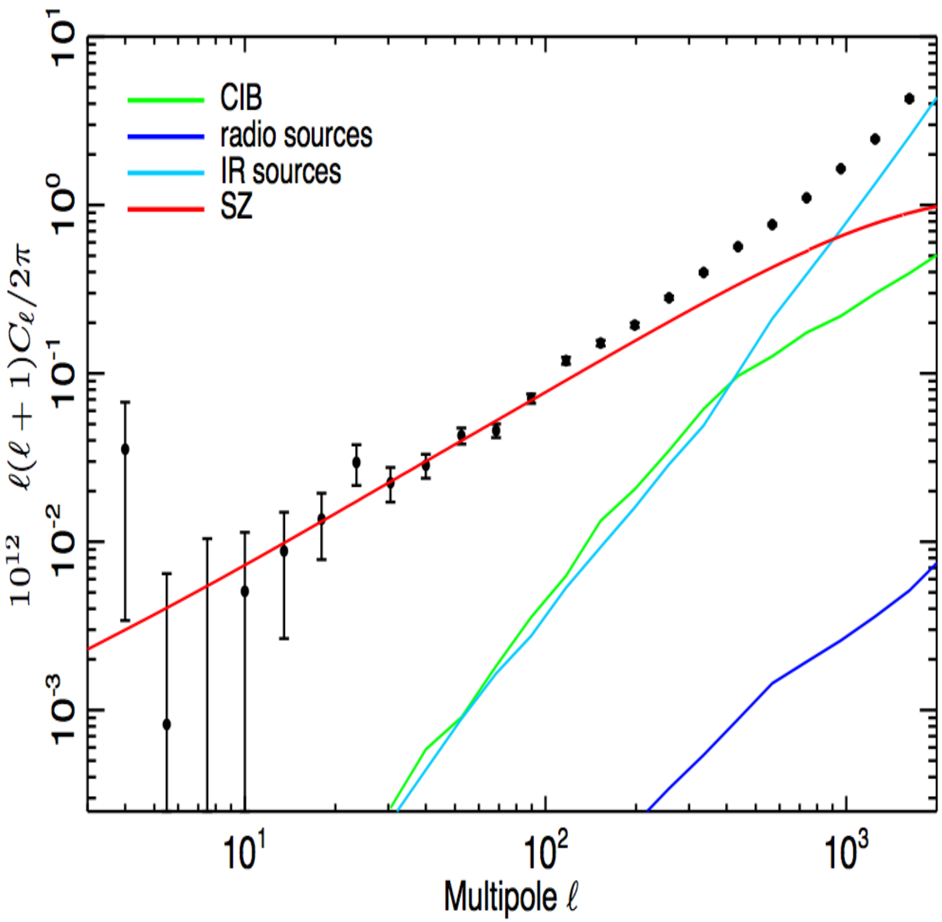
Main foreground contributions

➡ Galactic thermal dust at large angular scales - mask galactic emission on 50% of the sky

➡ cosmic infrared background and point sources at small angular scales - use physically motivated model + mask strong sources

★ Four component model : **tSZ** + clustered **CIB** + **Point sources**

$$C_l = C_l^{tSZ} + A^{CIB} \times C_l^{CIB} + A^{RS} \times C_l^{RS} + AI^{RS} \times C_l^{IRS} + C_l^{CN}$$



- **tSZ**: 2-halo model; ***Tinker et al 2008*** mass function; ***Arnaud et al 2010*** pressure profile; mass bias (1-b) = 0.8 or 0.6

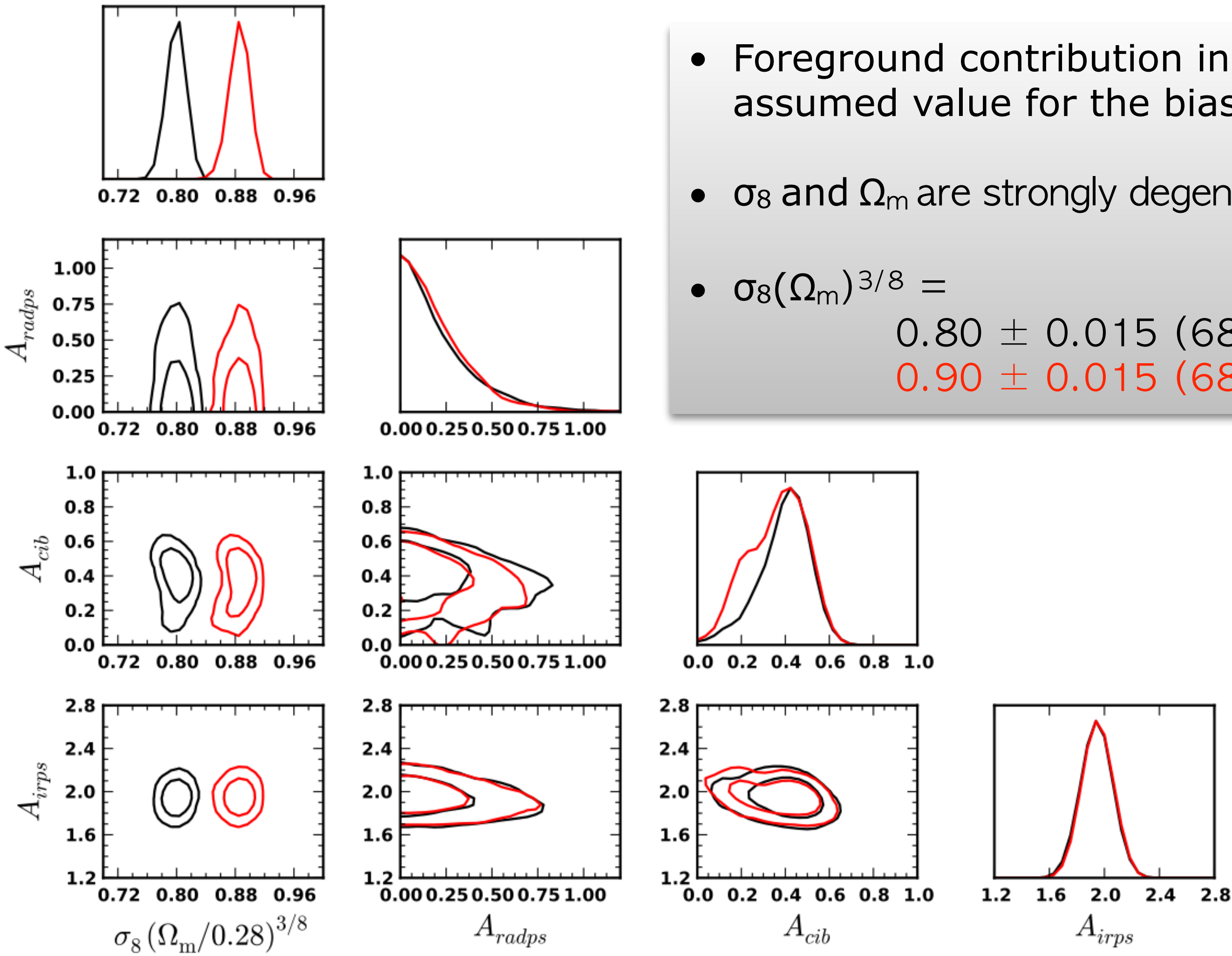
[Taburet et al 2009,2010,2011]

- clustered ***CIB***: best-fit frequency auto and cross-power spectra for the 6 HFI bands from Planck 2013 XXX results- 5% uncertainties on cross correlation coefficients accounted for

- ***Point sources***: number count models for the radio (Tucci et al 2011) and infrared (Bethermin et al 2012) sources - same as for CIB analysis

JF. Macias-Perez
on behalf of the **Planck Collaboration**

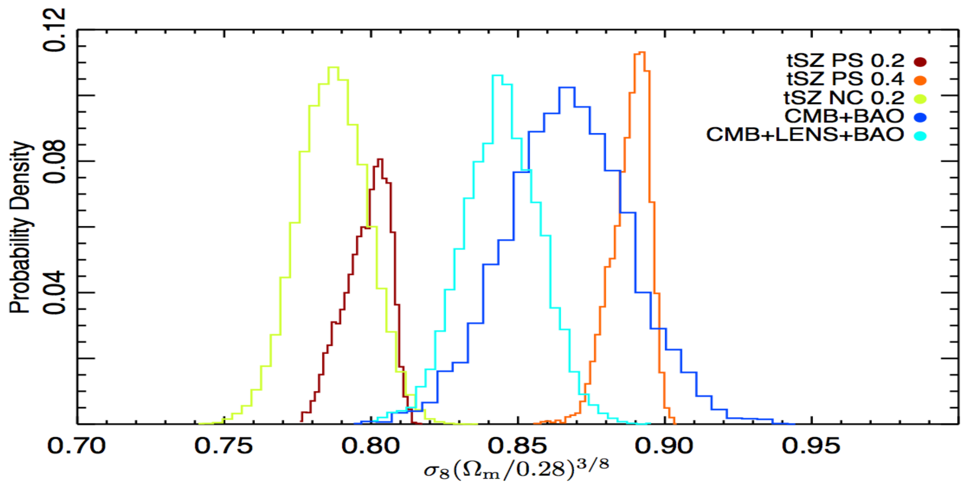
Use a MCMC analysis to fit simultaneously σ_8, Ω_m, A^{CIB}, A^{IRS}, A^{RS} fixing the mass bias



- Foreground contribution independent of the assumed value for the bias
- σ_8 and Ω_m are strongly degenerated
- $\sigma_8(\Omega_m)^{3/8}$ =
  0.80 ± 0.015 (68% C.L.) 〔(1-b) =0.8〕
  0.90 ± 0.015 (68% C.L.) 〔(1-b) =0.6〕

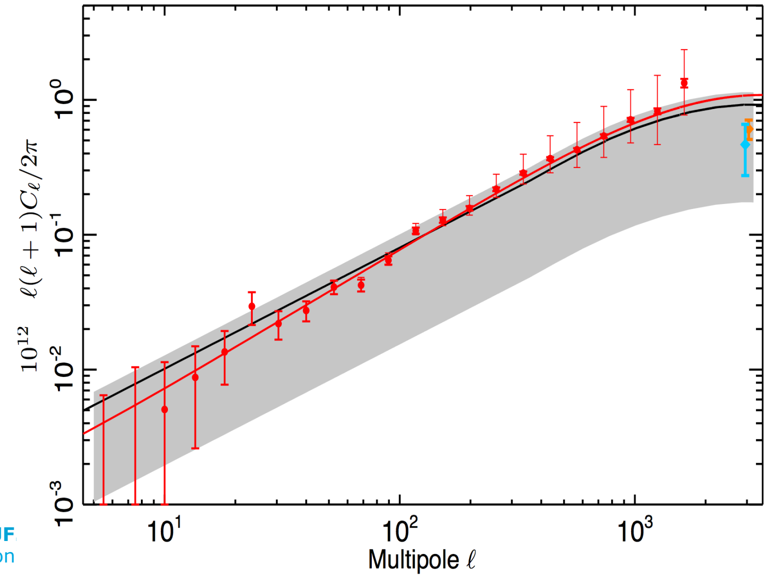
Consistency with CMB analysis and cluster physics uncertainties

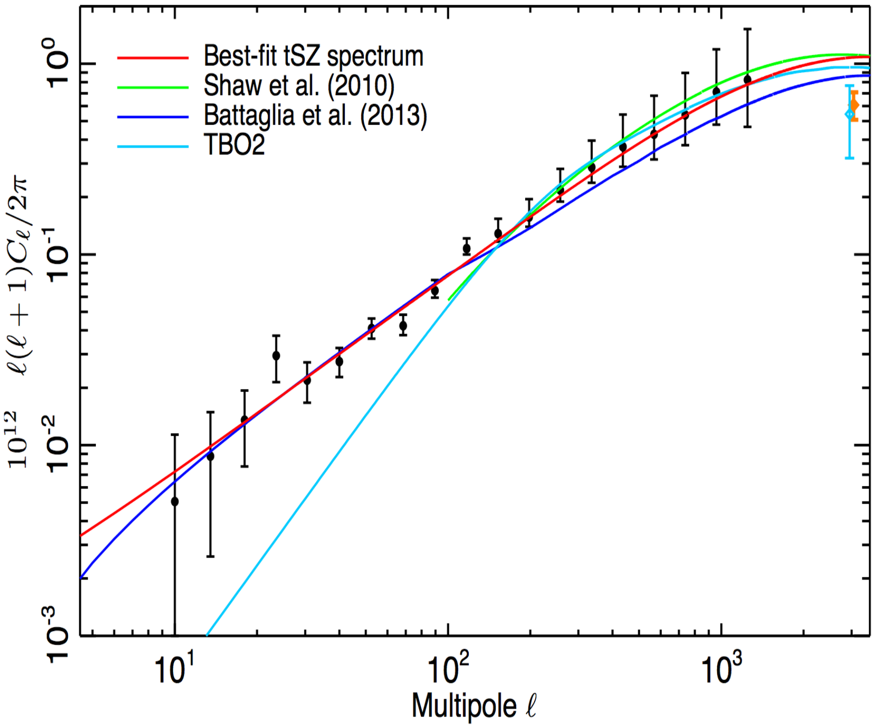
- Measured σ_8 and Ω_m are inconsistent with CMB results unless large bias is assumed



Physical model dependency needs to be study in more details: mass function, pressure profile, gas physics, ...

However we measure the same tSZ power





Outline

- y-map reconstruction and characterisation
- doing cluster physics with the y-map
- cosmology with the y-map
  - angular power spectrum
  - higher order statistics

1D-PDF analysis: asymmetry of the distribution

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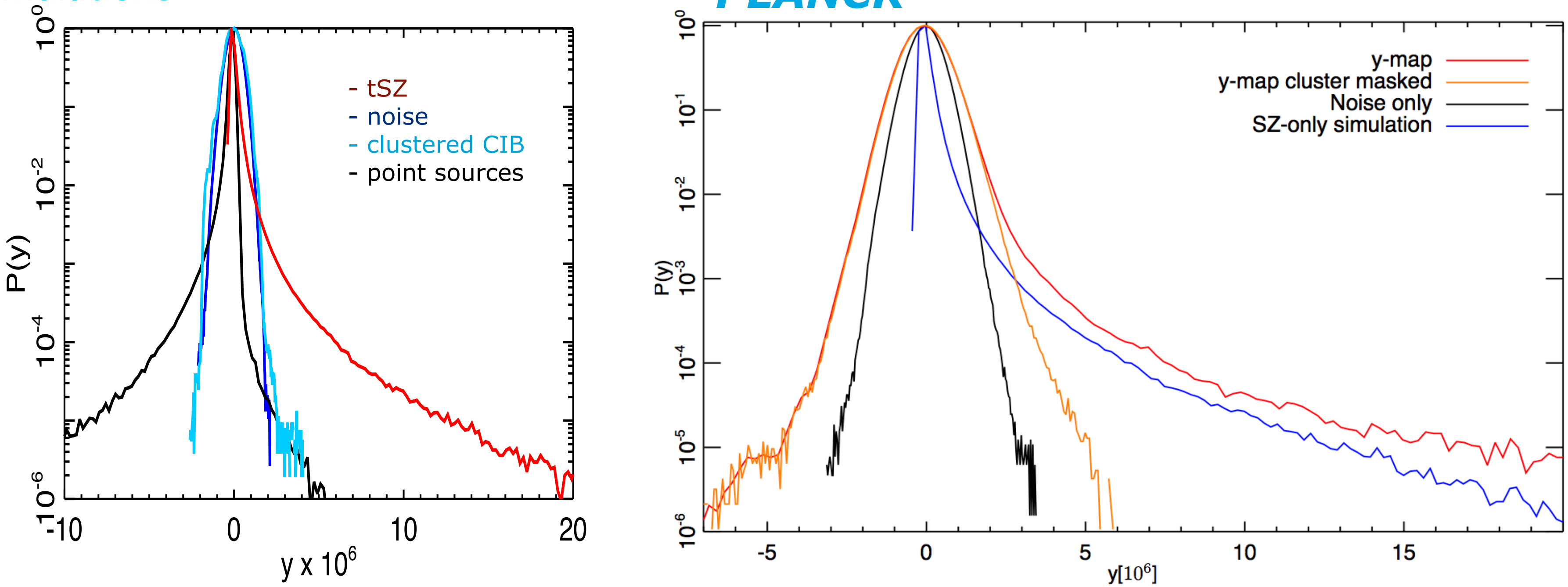
Use a signal-to-noise filter in harmonic space to enhance tSZ signal

Simulations

PLANCK



After filtering tSZ signal dominates:

- 1D-PDF shows a positive tail consistent with tSZ effect (dominated by PSZ2 clusters)
- from skewness (proportional to σ_8^{10-11}) we find $\sigma_8 = 0.78 \pm 0.02$ (68% C.L.)
- fit to the 1D-PDF using [Hill et al 2014] method we find $\sigma_8 = 0.77 \pm 0.02$ (68% C.L.)

Bispectrum analysis

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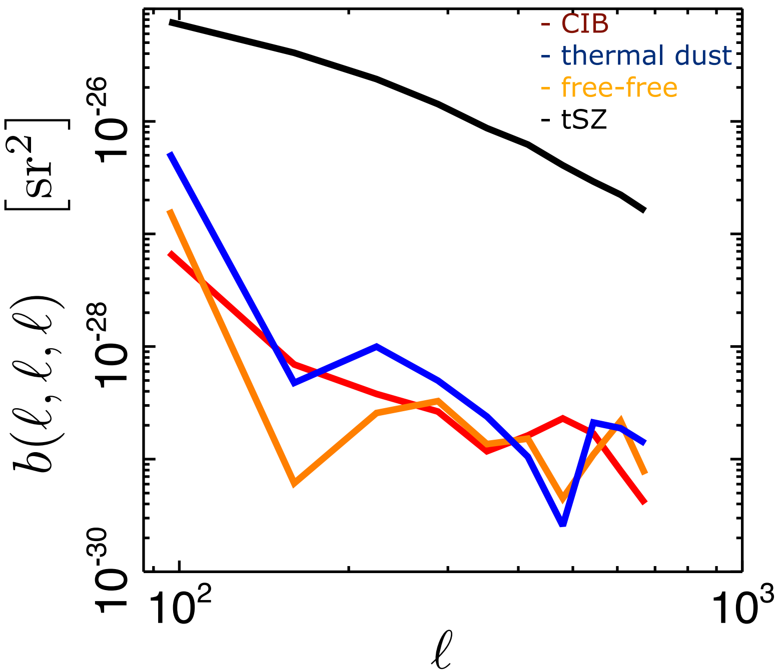
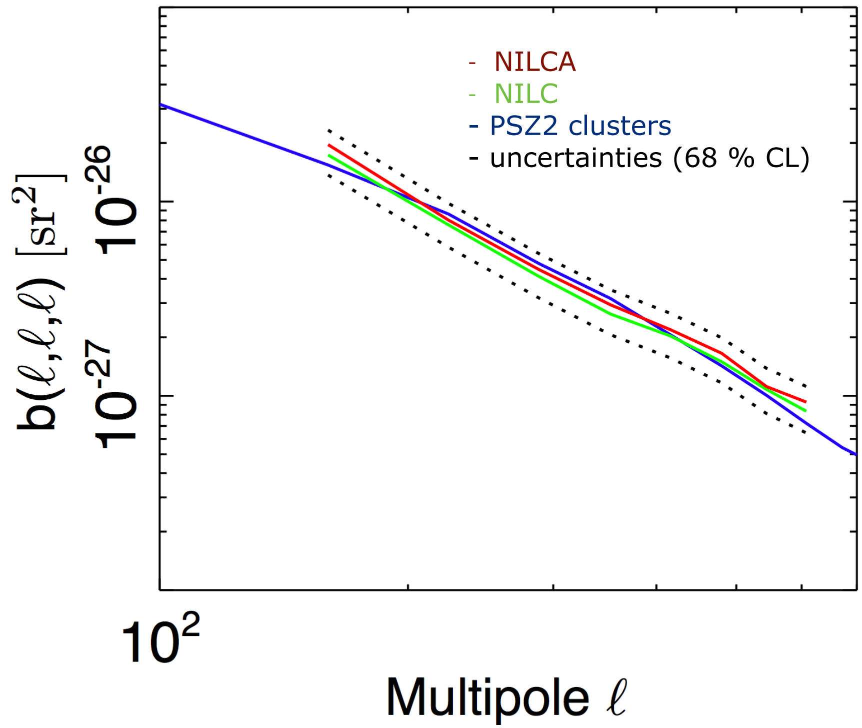
Compute bispectrum for various configurations [Lacasa et al 2012]

Simulations Equilateral



PLANCK



- the bispectrum of the y-map is dominated by the tSZ signal
- Planck provides first measurement of the tSZ effect bispectrum
- dominated by the contribution from PSZ2 clusters
- bispectrum amplitude scales as σ_8^{10-12} and so $\sigma_8 = 0.74 \pm 0.04$ (68% C.L.)

Conclusions

planck

✓Planck allows us to construct nearly full sky Compton parameter maps

✓We have performed exhaustive characterisation and validation of those maps

✓A wealth of exciting cluster physics can be extracted from those maps (scaling relations, pressure profiles, diffuse medium studies, shocks in merging system, etc)

✓The Planck y-map provides various independent cosmological probes which are consistent with more traditional number counts studies (Nabila's talk)

✓ Cosmology with clusters is limited by the understanding and modelling of cluster physics, not by statistics !

✓Planck y-maps have been delivered to the community with the 2015 release (see the Planck Legacy Archive or email us)

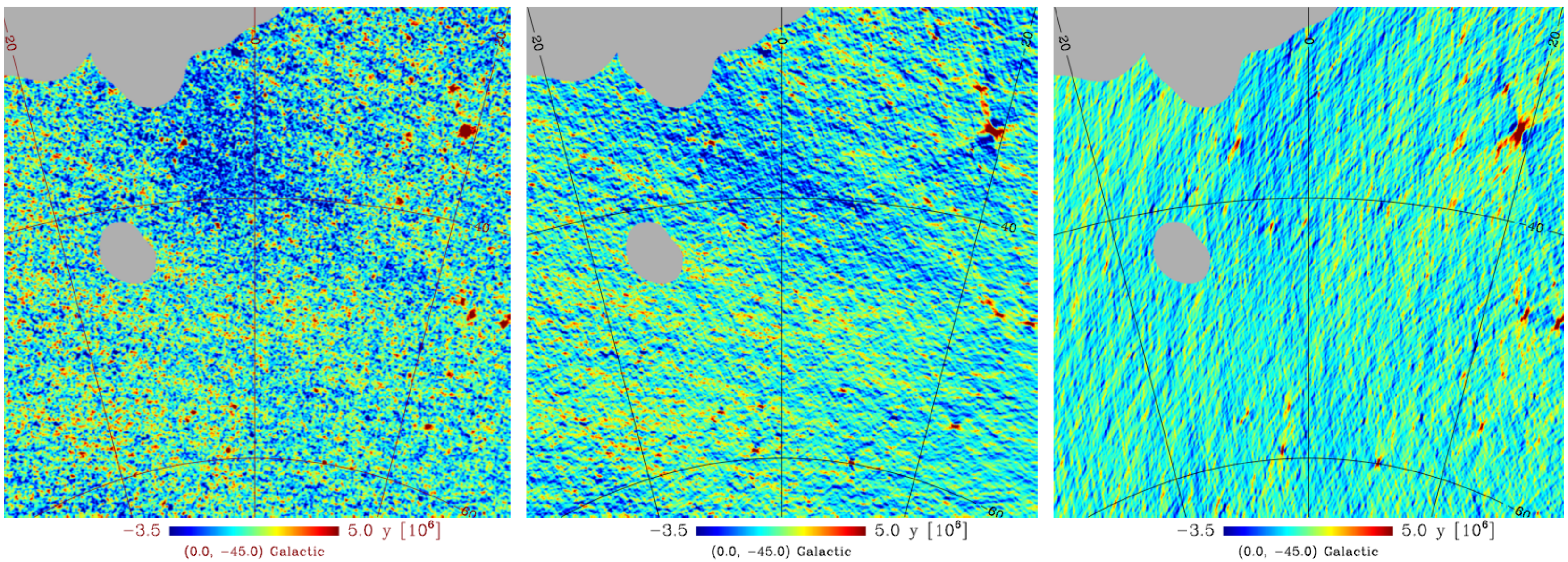
The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

Backup slides

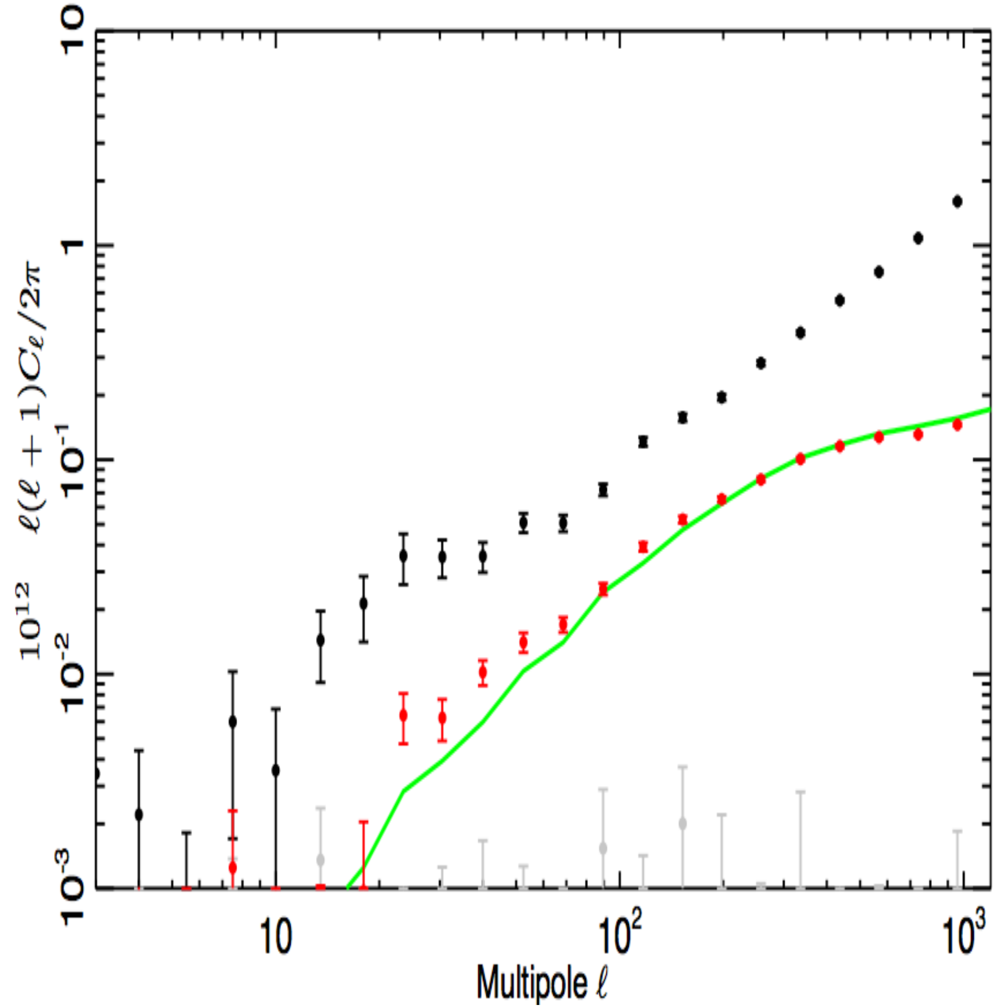
Stripes in the y-map

planck



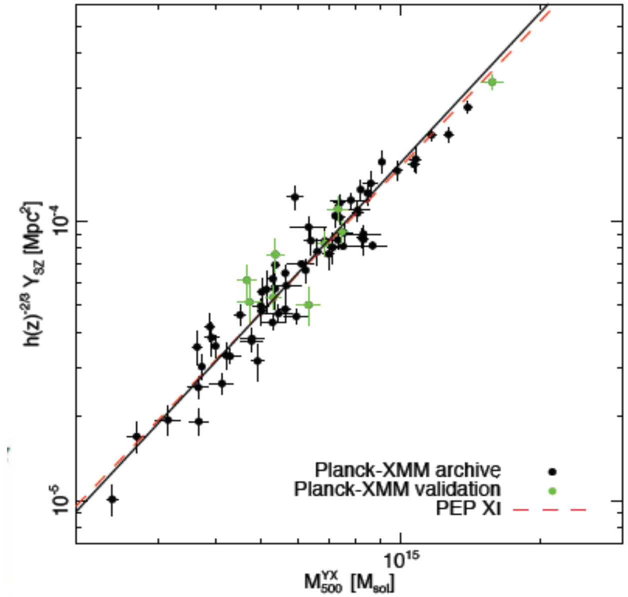
Power spectrum analysis IV: PSZ2 detected clusters

- Simulate detected clusters
- Mask all *Planck* detected point sources from 100-857 GHz
- A significant fraction of the observed signal is due PSZ2 clusters
- Clear indication of signal from unresolved clusters and diffuse structures



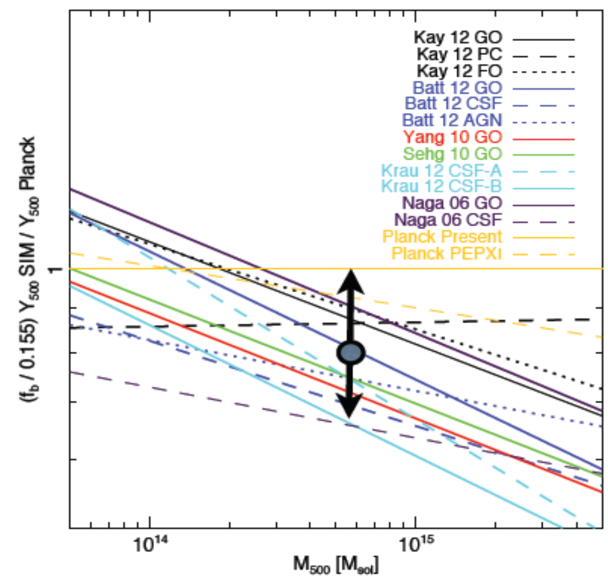
Scaling relation and bias

- Use 71 clusters in the sample with good XMM data
- Scaling relation Y_{SZ}-M_{500} is re-extracted with Xray size & position vs M^{YX}



$$E^{-\beta}(z)\left[\frac{D_A^2(z)\,\bar{Y}_{500}}{10^{-4}\,\mathrm{Mpc}^2}\right] = Y_*\left[\frac{h}{0.7}\right]^{-2+\alpha}\left[\frac{(1-b)\,M_{500}}{6\times10^{14}\,\mathrm{M_{sol}}}\right]^{\alpha}$$

- lognormal scatter on Y
- Include also a mass bias as observed in numerical simulations



$$\longrightarrow\ (1-b) = 0.8\ in\ [0.7-1.0]$$

Halo model for the tSZ effect power spectrum

$$C_l^{tSZ} = C_l^{1halo} + C_l^{2halo}$$

$$C_\ell^{1\text{halo}} = \int_0^{z_{\max}} dz \frac{dV_c}{dz d\Omega} \int_{M_{\min}}^{M_{\max}} dM \frac{dn(M,z)}{dM} |\tilde{y}_\ell(M,z)|^2$$

Tinker et al 2008
mass function

$$\frac{dn}{dM} = f(\sigma)\frac{\bar{\rho}_m}{M}\frac{d\ln\sigma^{-1}}{dM}$$

$$f(\sigma) = A\left[\left(\frac{\sigma}{b}\right)^{-a} + 1\right] e^{-c/\sigma^2}$$

$$\sigma^2 = \int P(k)\hat{W}(kR)k^2\, dk,$$

$$C_\ell^{2\text{halos}} = \int_0^{z_{\max}} dz \frac{dV_c}{dz d\Omega} \times \left(\int_{M_{\min}}^{M_{\max}} dM \frac{dn(M,z)}{dM} |\tilde{y}_\ell(M,z)|\, B(M,z)\right)^2 P(k,z)$$

Arnaud et al 2010
pressure profile

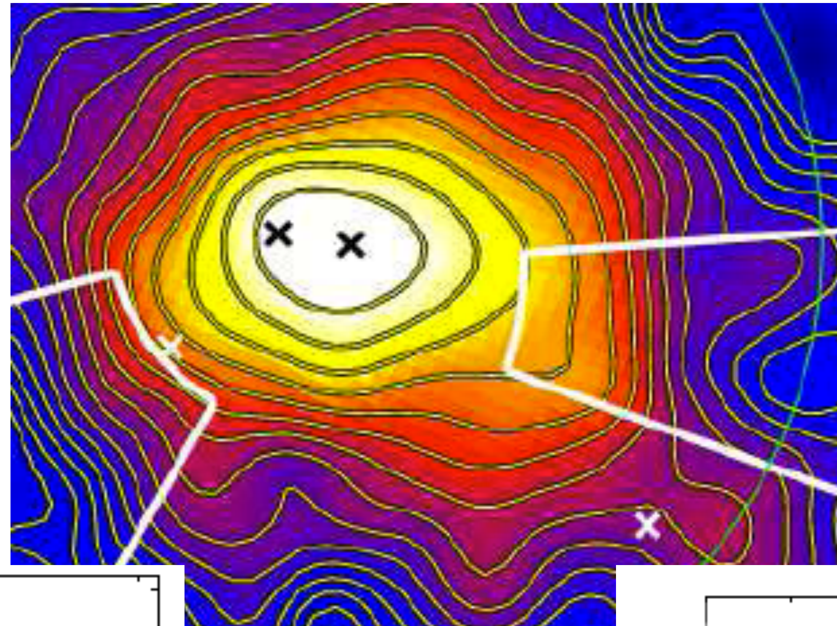
$$\tilde{y}_\ell(M,z) = \frac{4\pi r_s}{l_s^2}\left(\frac{\sigma_T}{m_e c^2}\right)\int_0^\infty dx\, x^2 P_e(M,z,x)\frac{\sin(\ell_x/\ell_s)}{\ell_x/\ell_s}$$

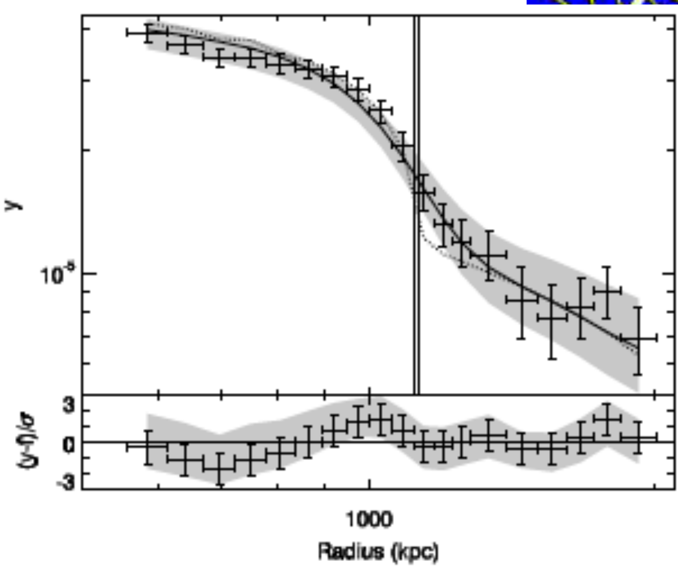
$$P(r) = P_{500}\left[\frac{M_{500}}{3\times10^{14}\,h_{70}^{-1}\,M_\odot}\right]^{\alpha_P+\alpha'_P(x)} \mathbb{p}(x)$$
$$= 1.65\times10^{-3}\, h(z)^{8/3}\left[\frac{M_{500}}{3\times10^{14}\,h_{70}^{-1}\,M_\odot}\right]^{2/3+\alpha_P+\alpha'_P(x)} \times \mathbb{p}(x)\quad h_{70}^2\,\mathrm{keV\,cm^{-3}}$$

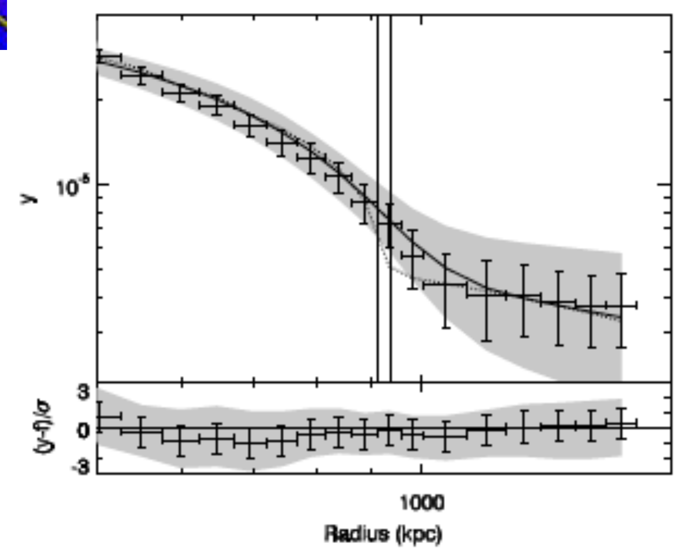
$$\mathbb{p}(x) = \frac{P_0}{(c_{500}x)^\gamma\,[1+(c_{500}x)^\alpha]^{(\beta-\gamma)/\alpha}}$$

$[P_0, c_{500}, \Upsilon, \alpha, \beta, \alpha_P] = [3.130 h_{70}^{-3/2}, 1.156, 0.3292, 1.0620, 5.4807, 0.12]$ $\quad x = r/R_{500}$

Shocks in COMA



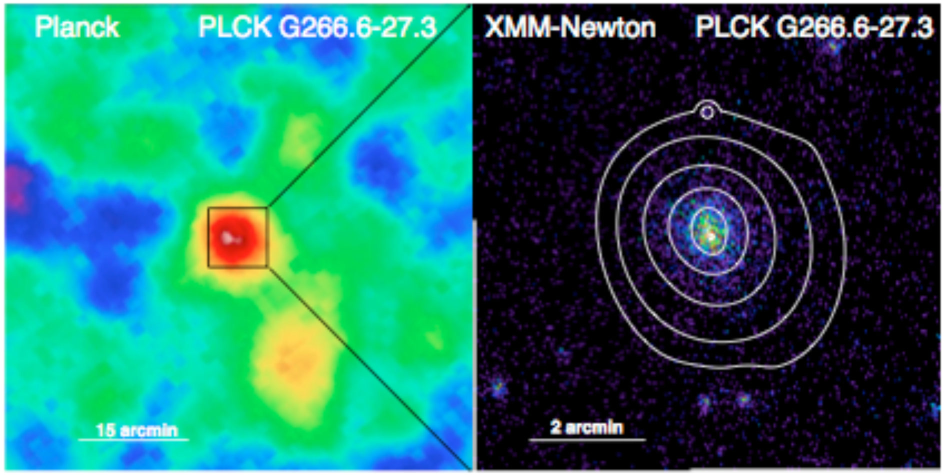




PLCK G266.6-27.3 a high redshift cluster

planck

2011A&A...536A..26P



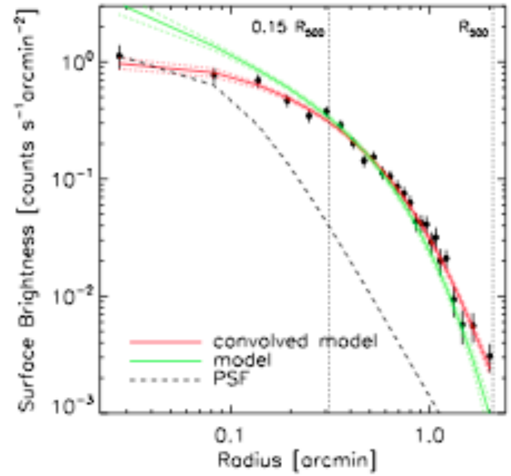


Table 1: Physical properties of PLCK G266.6−27.3 derived from *XMM-Newton* data.

Parameter	Value
z	0.94 ± 0.02
Abundance	0.44 ± 0.17 solar
R_{500}	0.98 ± 0.03 Mpc
M_{500}	$7.8^{+0.8}_{-0.7} \times 10^{14}\ M_\odot$
Y_X	$1.10^{+0.20}_{-0.17} \times 10^{15}\ M_\odot$ keV
T_X	$10.5^{+1.6}_{-1.4}$ keV
$T(< R_{500})$	$11.4^{+1.4}_{-1.2}$ keV
L_{500}([0.5–2.0] keV)	$14.2 \pm 0.5 \times 10^{44}$ erg s^{-1}
L_{500}([0.1–2.4] keV)	$22.7 \pm 0.8 \times 10^{44}$ erg s^{-1}

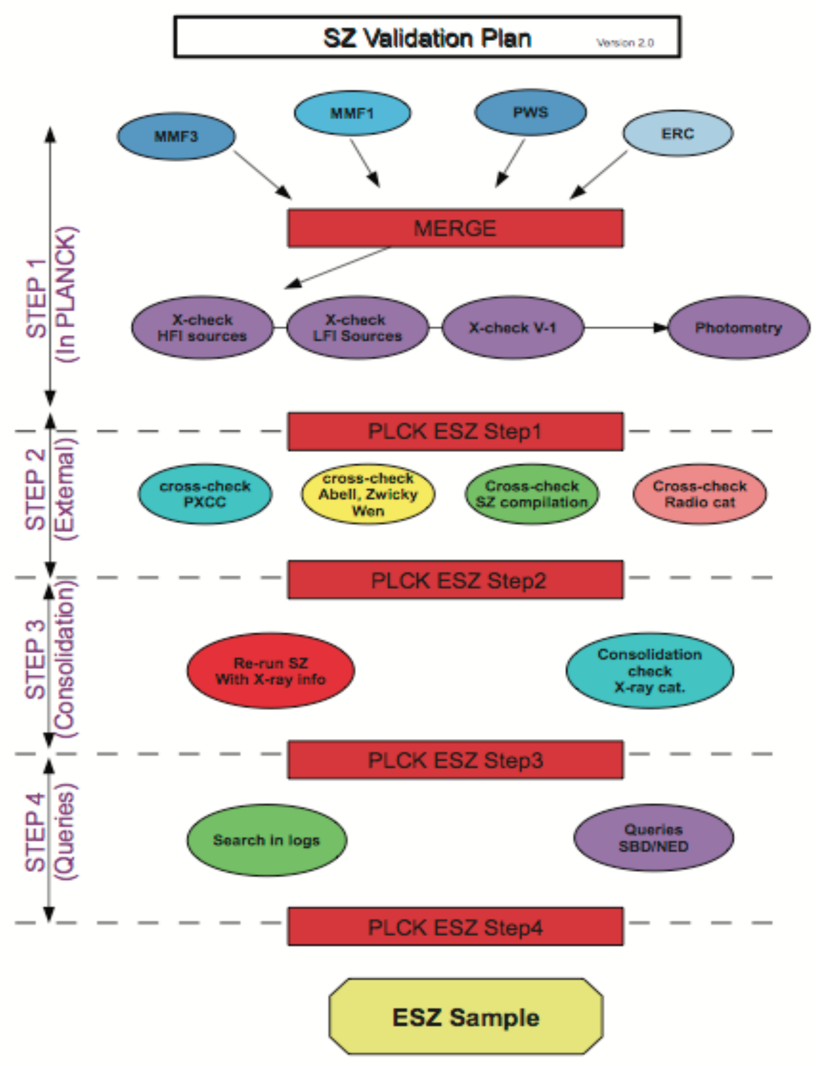
Table 2: SZ flux derived from *Planck* data with the reference value indicated in boldface.

Method	Definition	Value (10^{-4} arcmin^2)	θ_{500} (arcmin)
MMF blind	Y_{500}	5.6 ± 3.0	3.3 ± 2.8
PWS blind	Y_{500}	6.5 ± 1.8	3.9 ± 1.6
MMF X-ray prior	Y_{500}	**4.1 ± 0.9**	fixed
PWS X-ray prior	Y_{500}	5.3 ± 0.9	fixed
MILCA	Y_{tot}	5.9 ± 1.0	...

Notes. Uncertainties on the blind values take into account the size uncertainty.

Very peculiar cluster: very luminous in Xrays and very massive with respect to previously known clusters at z>0.5

The all sky Planck tSZ catalogue



Extraction methods:
- MMF1/3
- Powell snakes

Artifacts and Planck sources
- SSO objects
- cold cores, radio and IR sources

Component separation methods:
- MILCA
- NILC

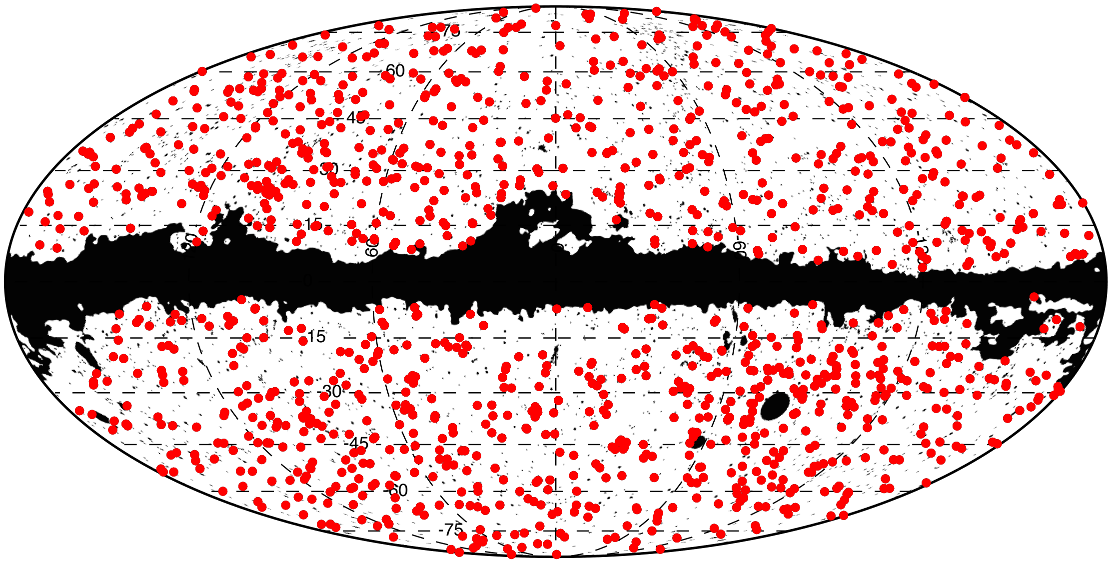
X-ray data
- XMM
  ROSAT
- RECESS MCXC catalogue

Optical data:
- MaxBCG

tSZ data:
- AMI

The all sky Planck tSZ catalogue

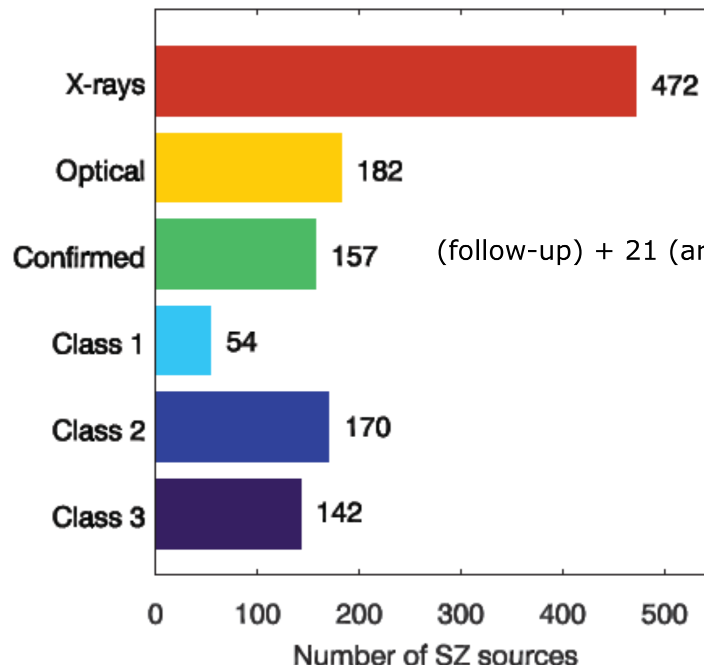
planck



2013arXiv1303.5089P

Catalogue of cluster candidates over 84 % of the sky

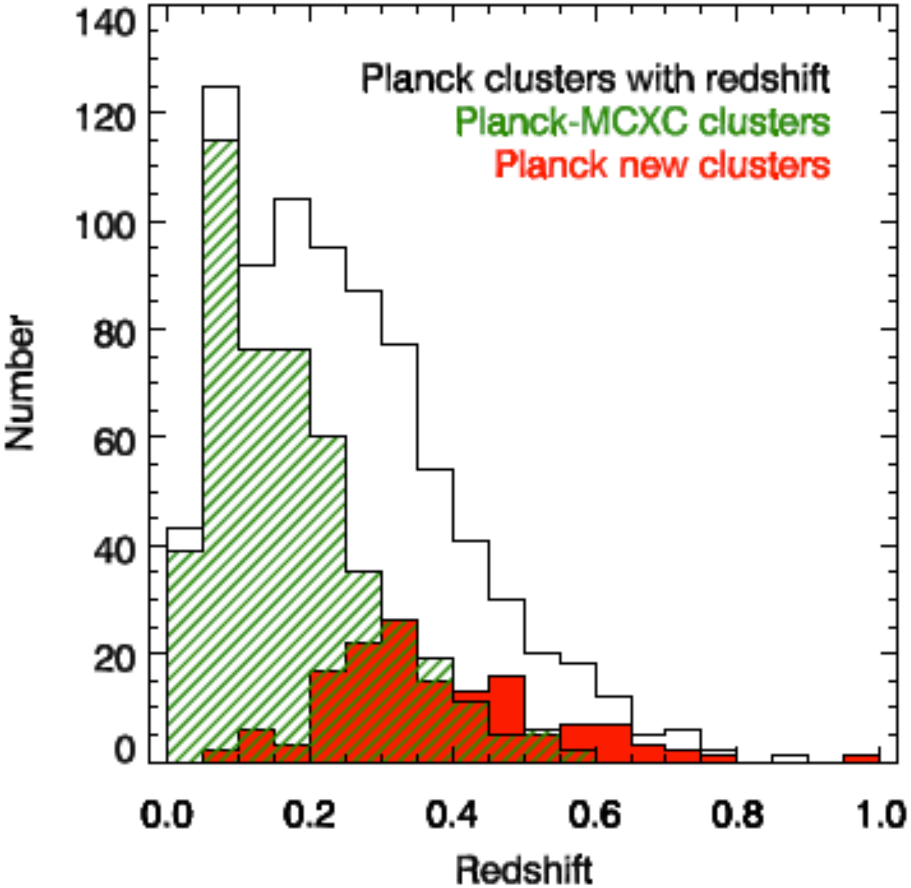
- 1227 clusters & candidates
  - 683 previously known
  - 178 new clusters
  - 366 candidates
- z in [0-1]
- M in [1~20] 10^{14} M_{sun}
- Mmed ~ 3.5 10^{14} M_{sun}
- see Planck 2013 XXIX

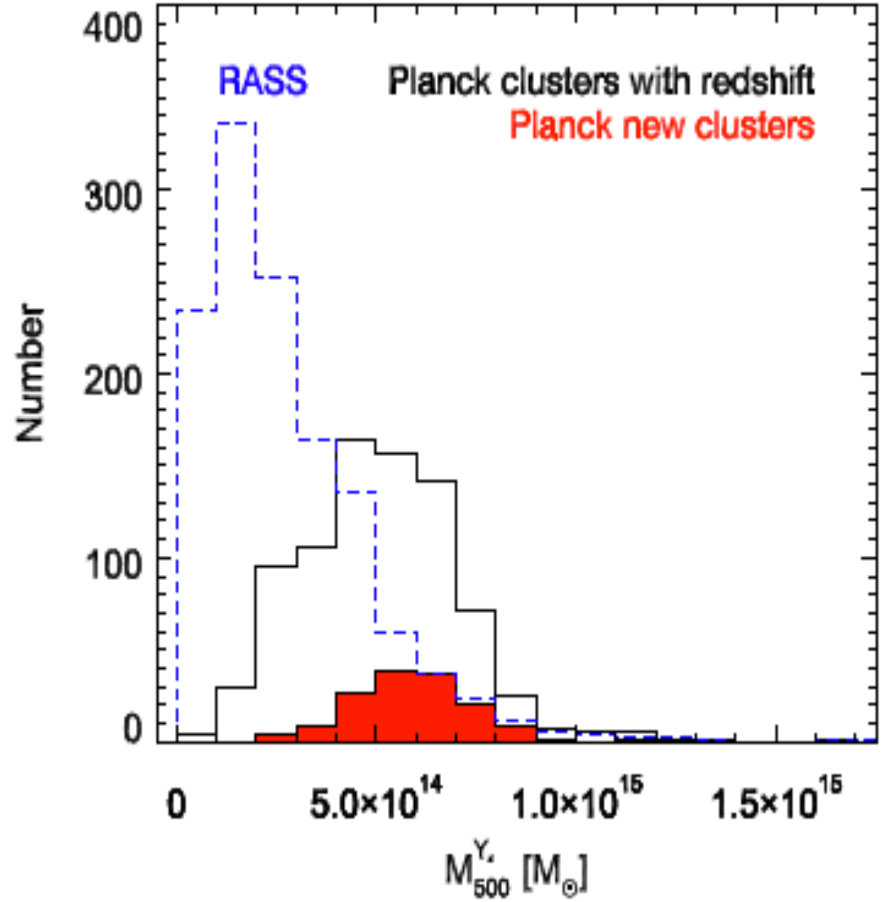


(follow-up) + 21 (archive data)

The all sky Planck tSZ catalogue

Planck new clusters populate high end of the distribution in redshift and mass





Cluster number counts

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The number of clusters as a function of mass and redshift depends strongly on cosmological parameters

$$\frac{dN}{dz} = \int d\Omega \int dM_{500}\, \hat{\chi}(z, M_{500}, l, b)\, \frac{dN}{dz\, dM_{500}\, d\Omega}$$

- We take as a reference the Tinker et al 2008 mass function
- We use scaling relations Y-M based on a sample of 71 Planck clusters
- Selection mass is obtained from Planck noise maps
- We use a S/N selected sample of 189 PSZ clusters
- Alternative scenarios are considered

The Planck cluster cosmological sample

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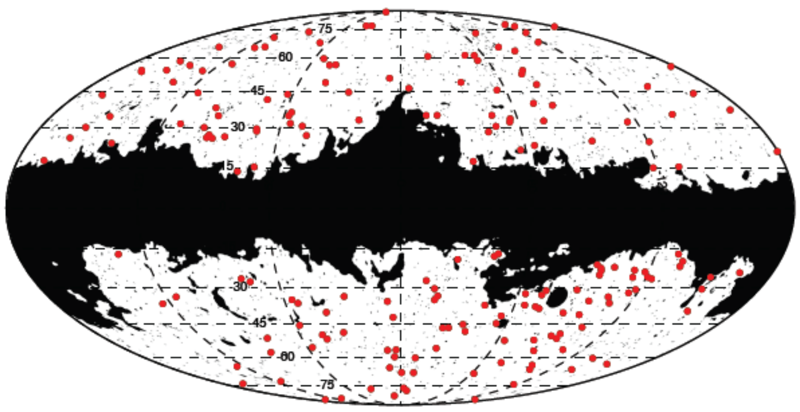
-Selected sample from a compromise between purity and large number of clusters

-Considered only the cleanest 65 % of the sky

✓189 clusters with S/N > 7 in MMF3

✓188 clusters with redshift

✓71 of them were used for scaling relation



➡ well characterized SZ selected sample

Completeness

-Noise maps from MMF method are obtained over all detection patches

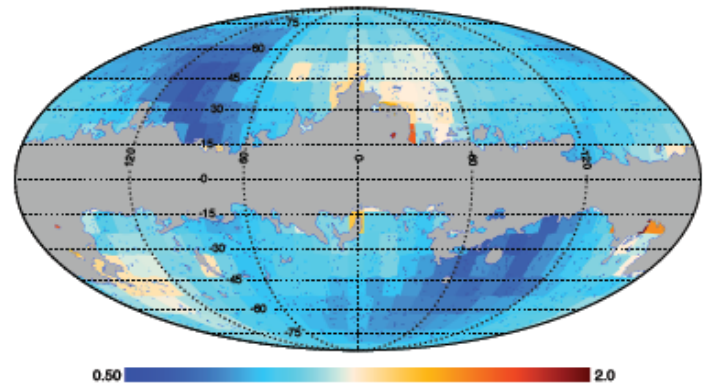
-Noise for each filter size

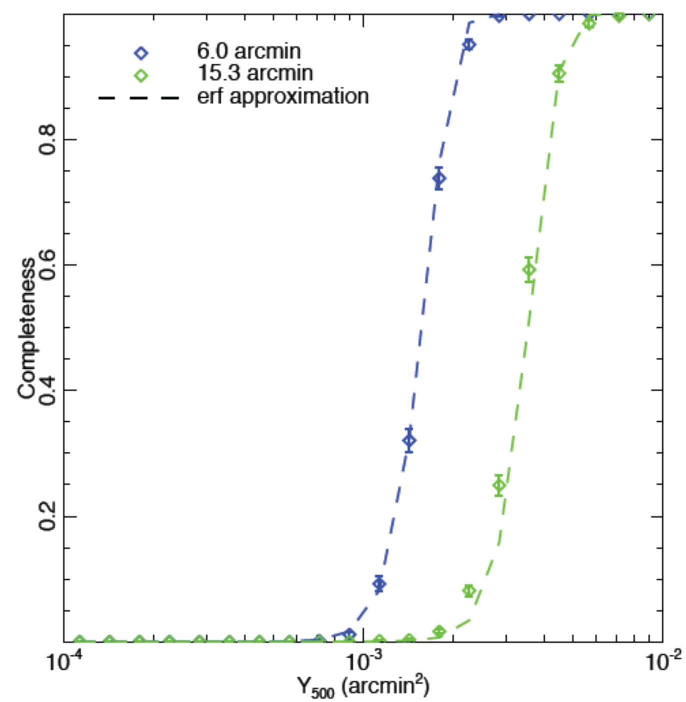
$$\longrightarrow \sigma_{Y_{500}}(\theta_{500}, l, b)$$

-Use as a reference analytic completeness

$$\chi_{\mathrm{erf}}(Y_{500}, \theta_{500}, l, b) = \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{Y_{500} - X\sigma_{Y_{500}}(\theta_{500}, l, b)}{\sqrt{2}\,\sigma_{Y_{500}}(\theta_{500}, l, b)}\right)\right]$$

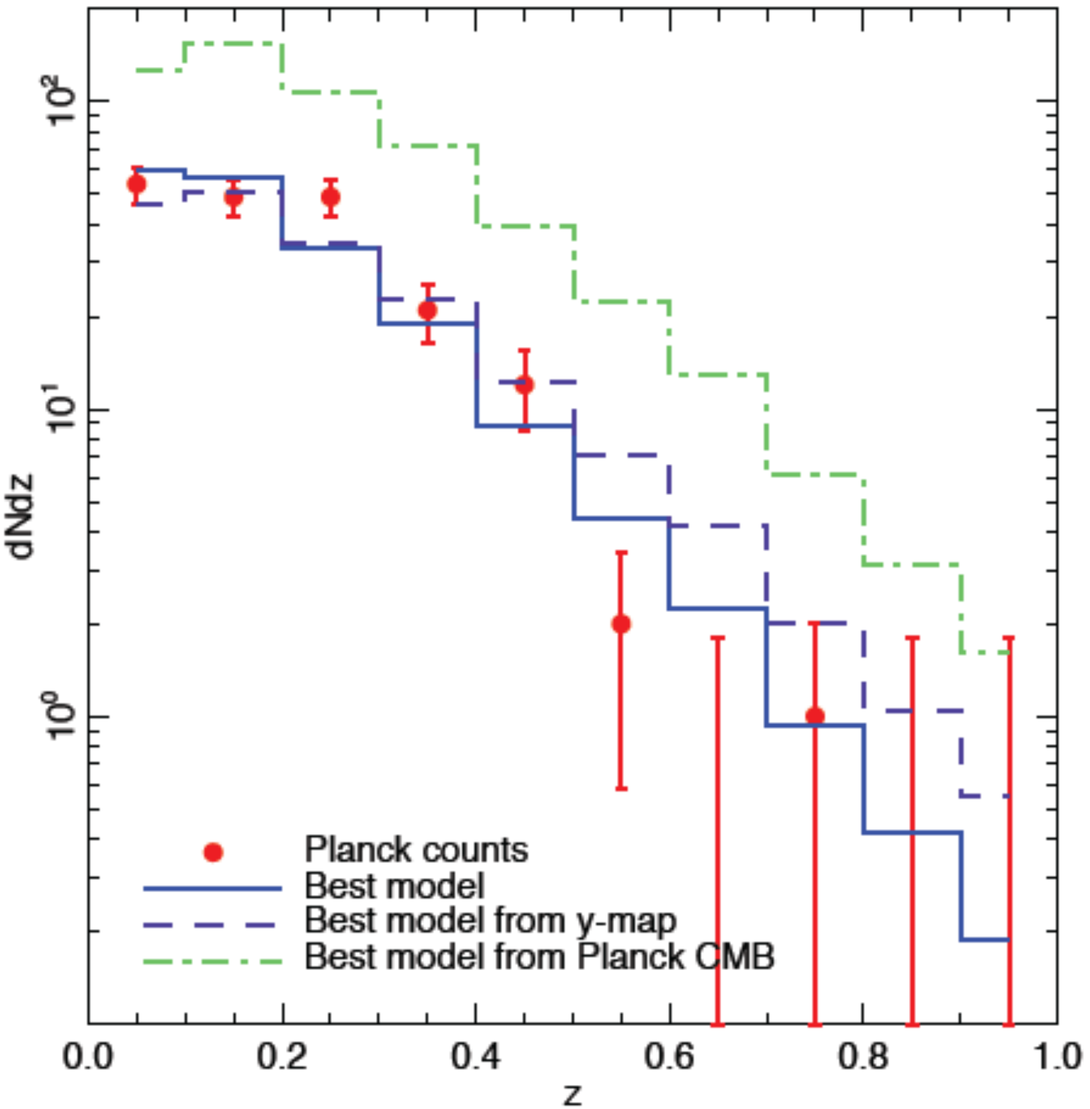
-Alternatively we cross check using Monte Carlo simulations





Planck cluster number counts

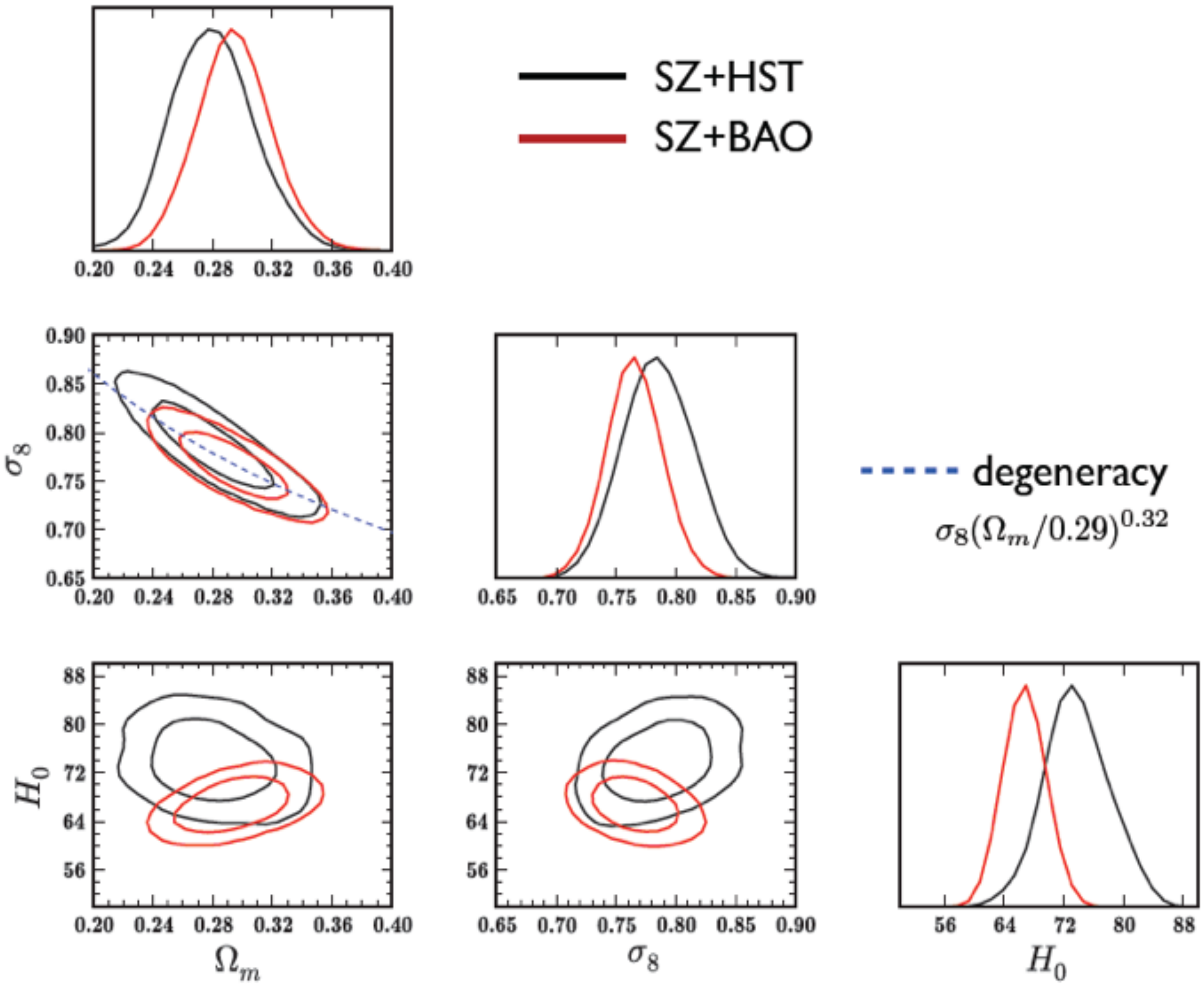
2013arXiv1303.5080P



We use a MCMC likelihood analysis to compare data and model

- We fit for σ_8, H0, Ω_m, ns, Ω_b
- Y*, α , $\sigma_{\log Y500}$ are considered as nuisance parameters with Gaussian priors
- We consider BBN priors and fix [1-b] = 0.8

Constraints on cosmological parameters



Consistency checks

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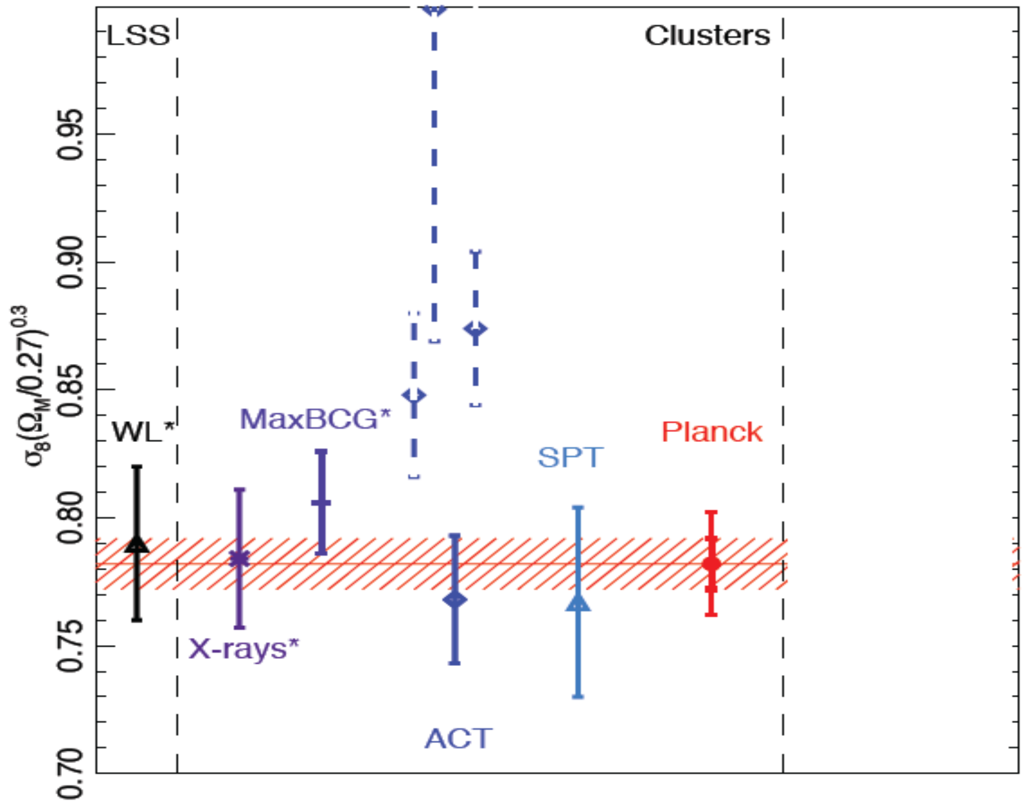
- Cosmological results do not depend on:
  - -the choice of the S/N (7/8)
  - -prior assumptions (BA0/ HST)
  - -mass function (Tinker et al/ Watson et al)
  - -prior on mass bias

	$\sigma_8(\Omega_m/0.27)^{0.3}$	Ω_m	σ_8	$1-b$
Planck SZ +BAO+BBN	0.782 ± 0.010	0.29 ± 0.02	0.77 ± 0.02	0.8
Planck SZ +HST+BBN	0.792 ± 0.012	0.28 ± 0.03	0.78 ± 0.03	0.8
MMF1 sample +BAO+BBN	0.800 ± 0.010	0.29 ± 0.02	0.78 ± 0.02	0.8
MMF3 S/N > 8 +BAO+BBN	0.785 ± 0.011	0.29 ± 0.02	0.77 ± 0.02	0.8
Planck SZ +BAO+BBN (MC completeness)	0.778 ± 0.010	0.30 ± 0.03	0.75 ± 0.02	0.8
Planck SZ +BAO+BBN (Watson et al. mass function)	0.802 ± 0.014	0.30 ± 0.01	0.77 ± 0.02	0.8
Planck SZ +BAO+BBN ($1-b$ in [0.7, 1.0])	0.764 ± 0.025	0.29 ± 0.02	0.75 ± 0.03	[0.7,1]

- Consistency between tSZ based results



Comparison to CMB results

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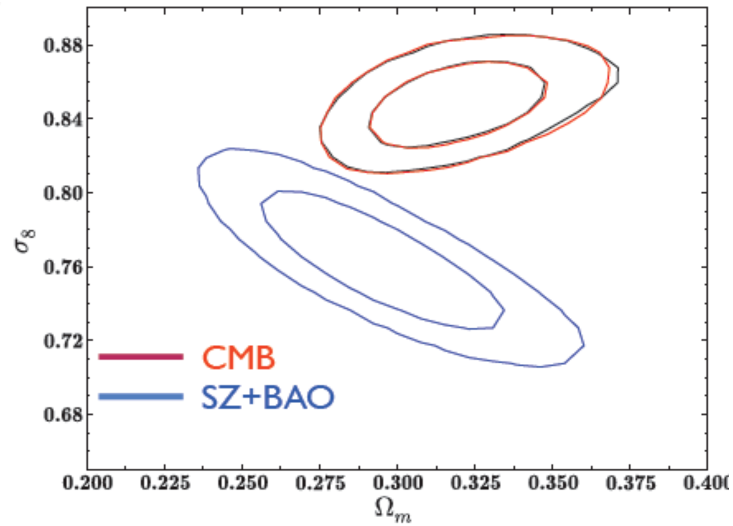
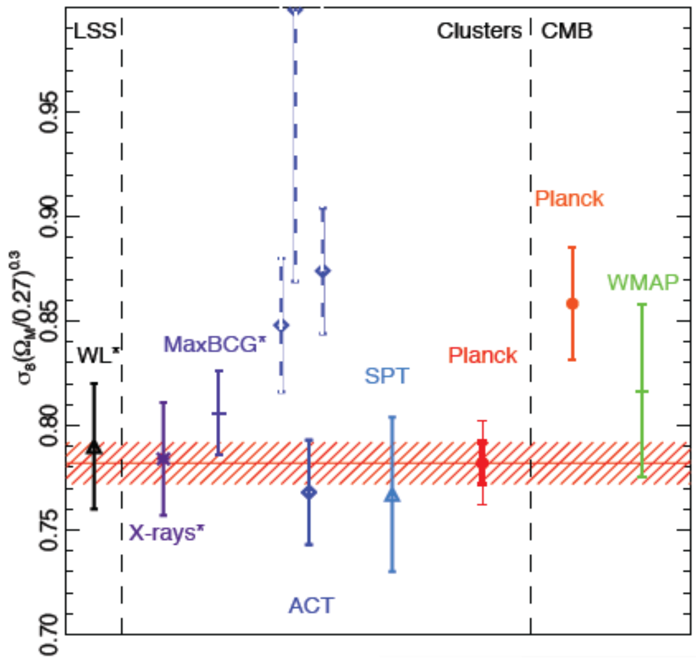
- 3 sigma tension with CMB measurements
- CMB finds larger values of σ_8 and Ω_m



Two options:

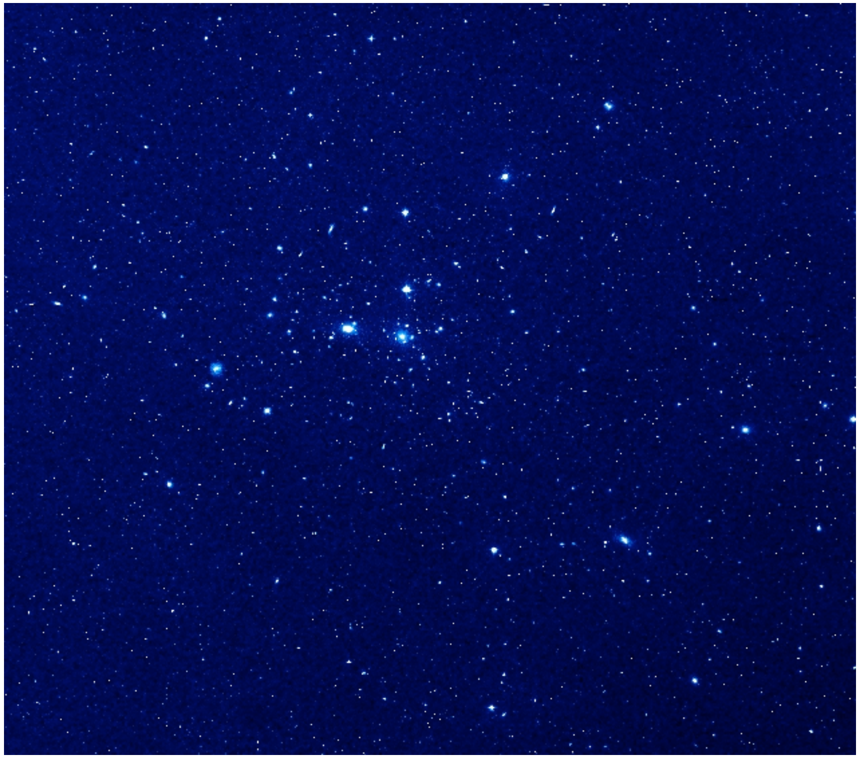
- Larger σ_8 value from clusters by changing scaling laws (so far based on M^{YX}) and /or mass bias (1-b = 0.55 solves the problem)
- Smaller σ_8 value from CMB by changing initial power spectrum and/or transfer function (massive neutrinos?)



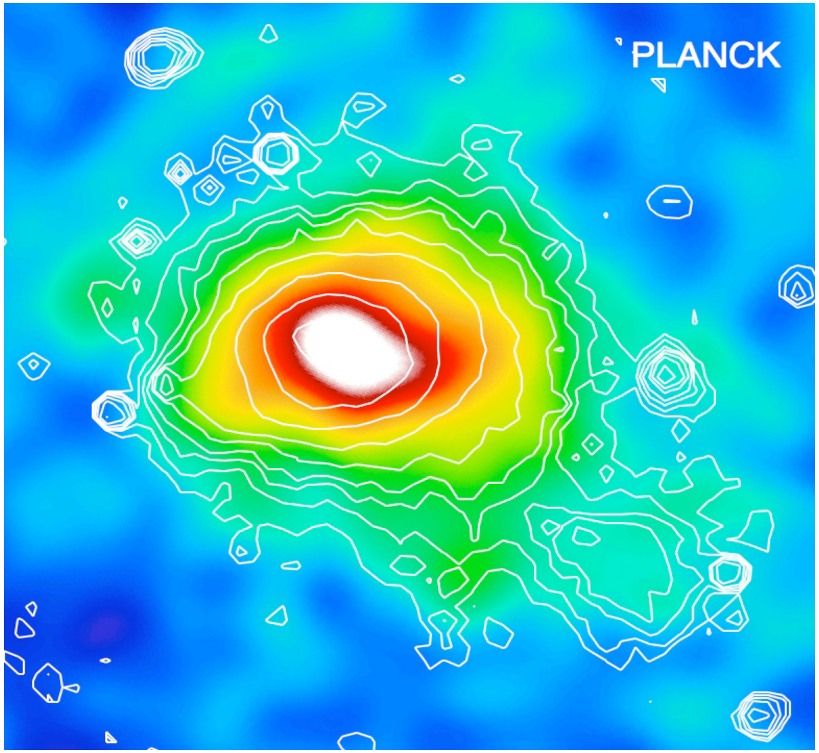
The COMA cluster

2013A&A...554A.140P

High sensitivity maps of nearby clusters like COMA: reliable outskirt detection



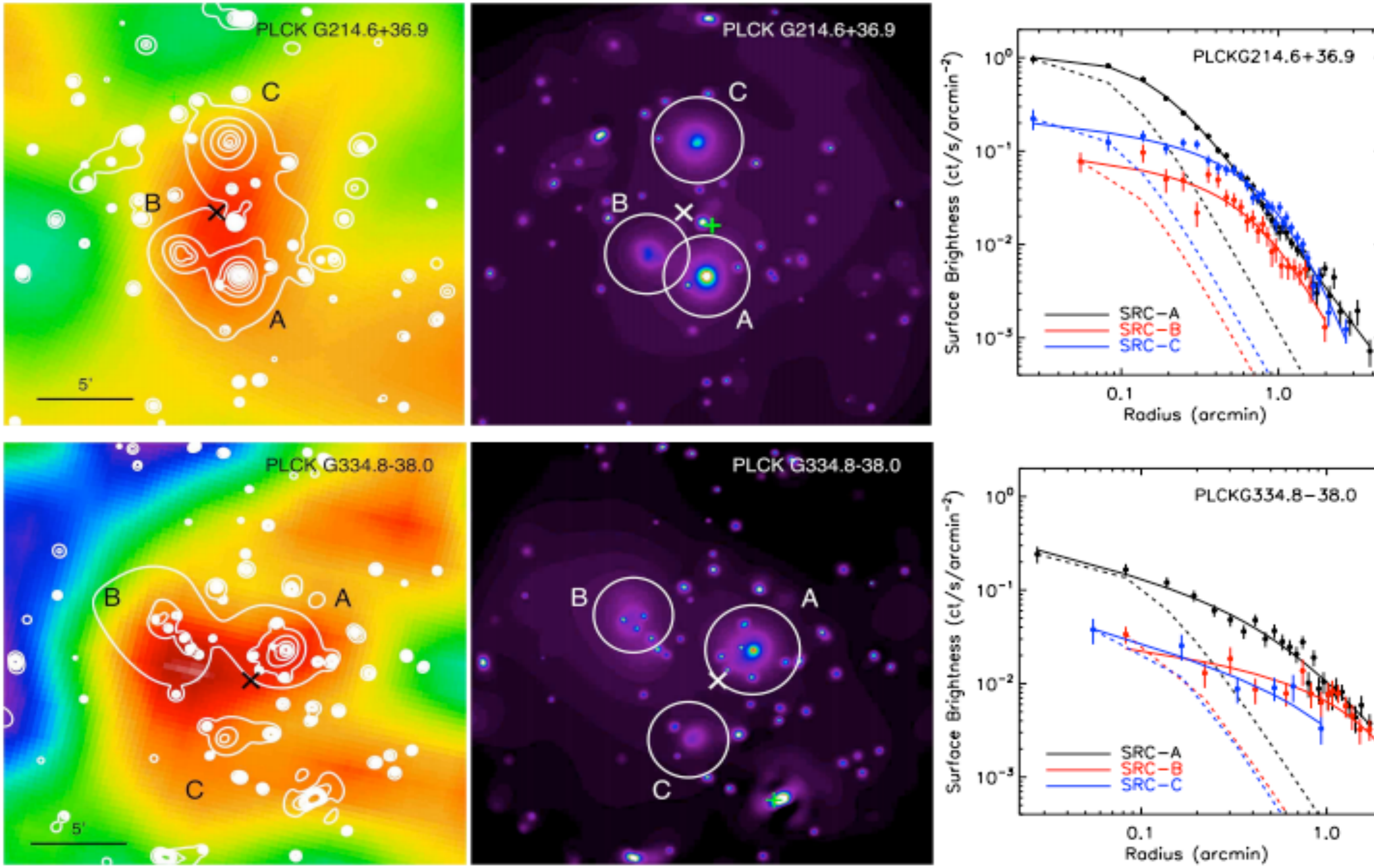
HST visible



PLANCK tSZ (colors) & XMM (contours)

Multiple cluster systems

2013A&A...550A.132P



Matter bridge on mergers

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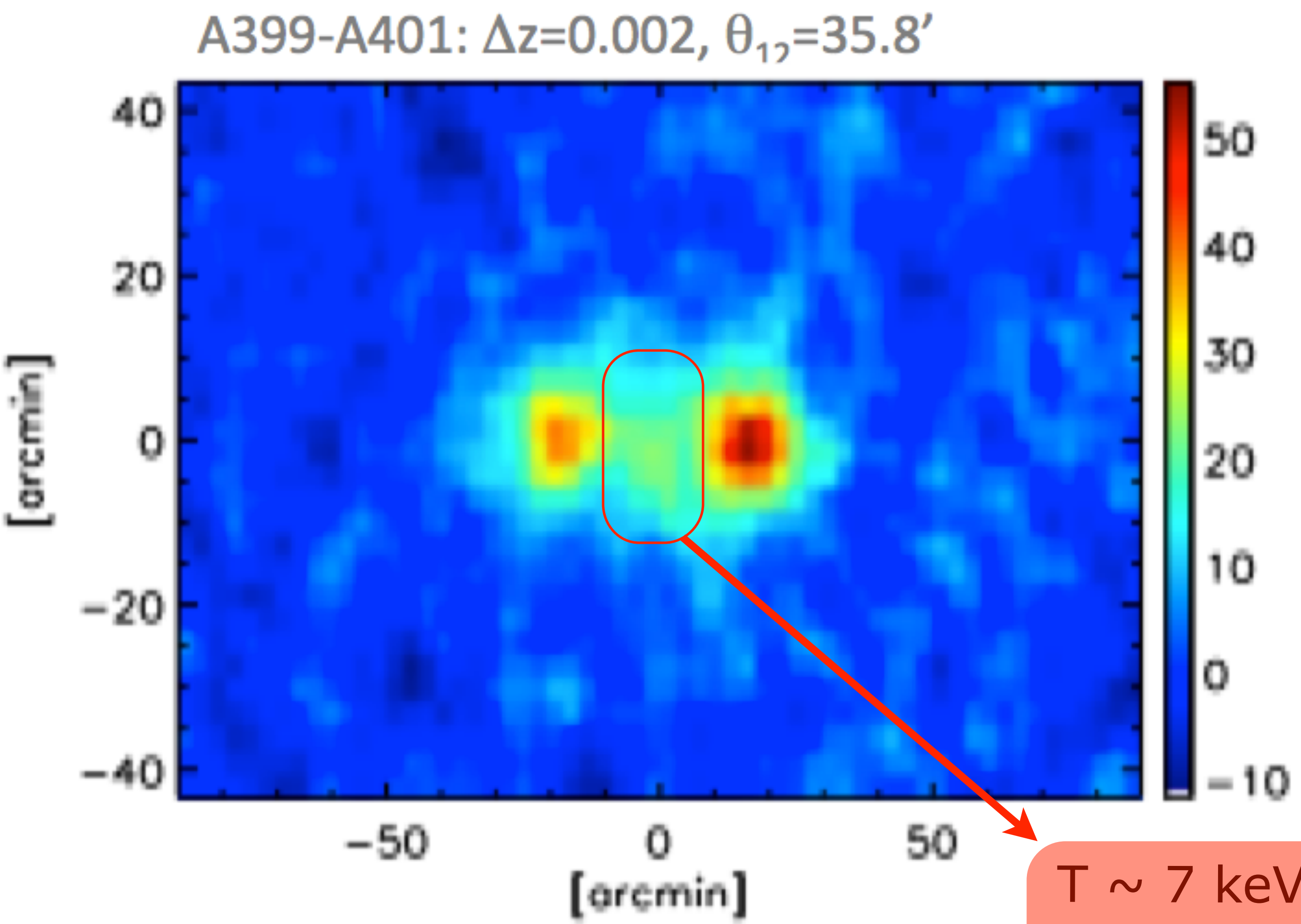
Planck observe a matter bridge between A399-A401

2013A&A...550A.134P



T ~ 7 keV

n_e ~ 3.7 10^{-4} cm^{-3}