Observations of Galaxy Clusters in the Microwave and the X-rays

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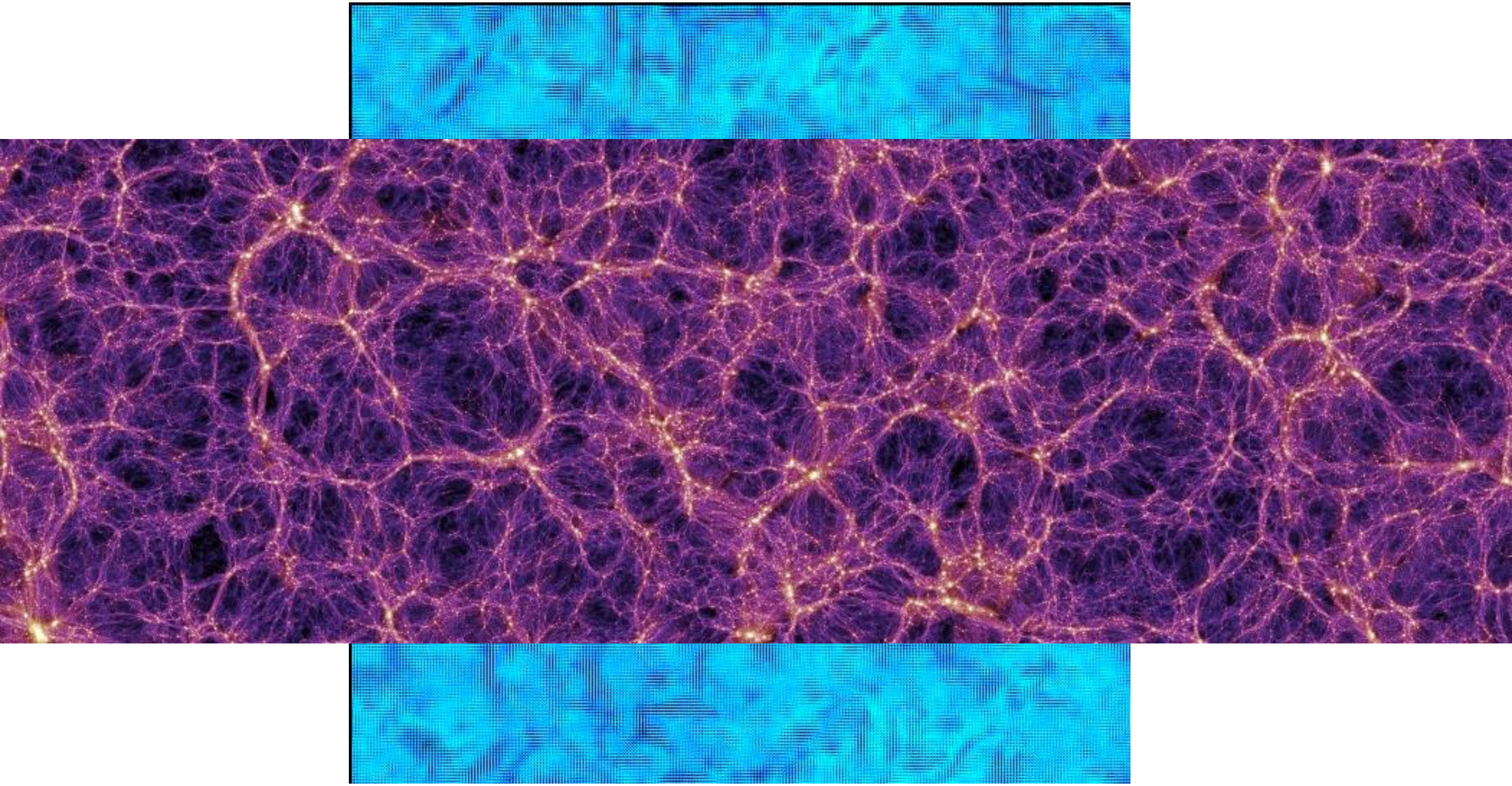
Overview

- Cosmic web and Clusters of Galaxies
- A very short overview of Clusters of galaxies observed in X-ray
- Observing clusters in the Microwaves: the SZ effect
- Ground and space SZ observations
- Review of some results obtained by Planck
- Show a preliminary result on the evolution of the cluster pressure profile
- Conclusions

Galaxy Clusters and the Cosmic web

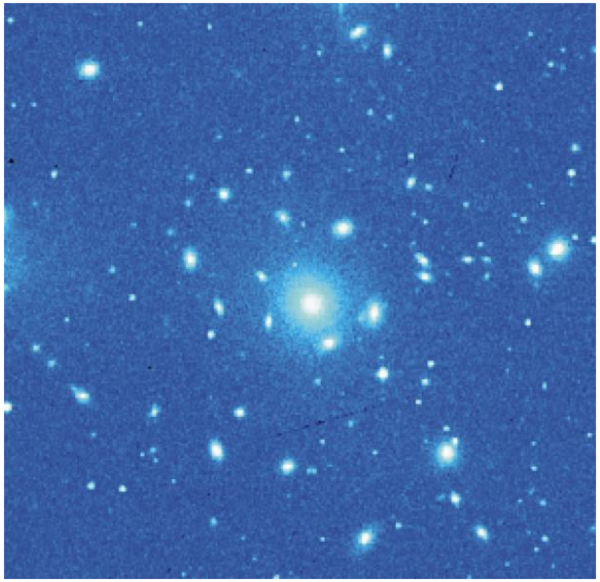


Cluster Components

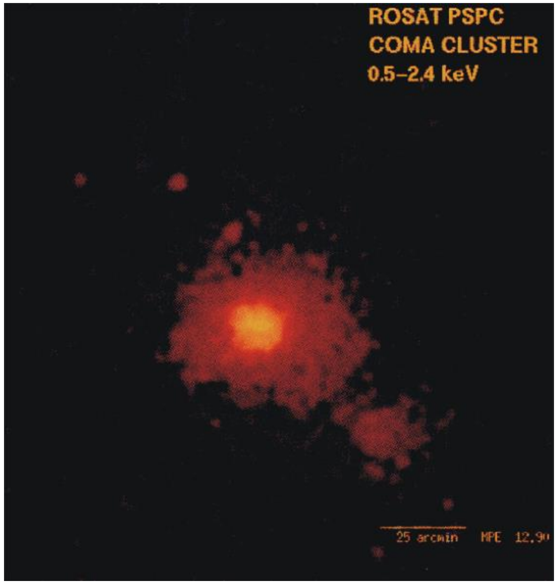
See also Introduction by G. Brunetti

1. Galaxies
2. Intergalactic Gas
3. Dark Matter

Thermal (v.s. Brunetti's Non Thermal)



Optical image

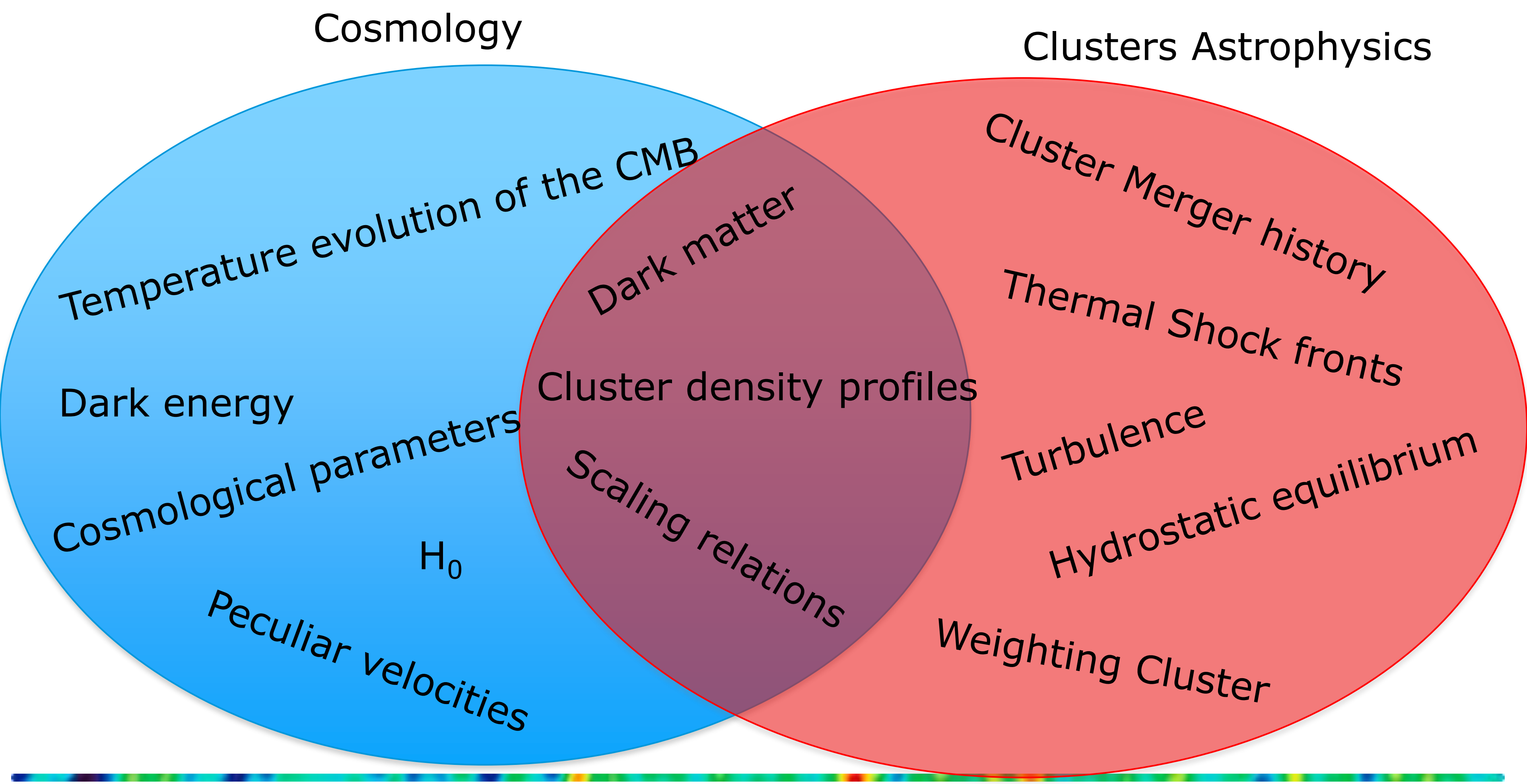


X-ray image

Gravitational Lensing

Investigations with clusters of galaxies observed in the X-ray Microwaves

Clusters of galaxies as powerful tools (just some keywords)



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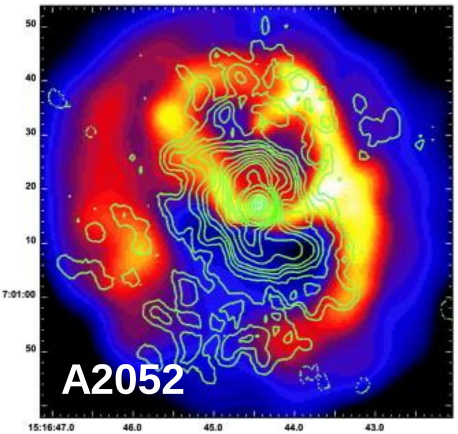
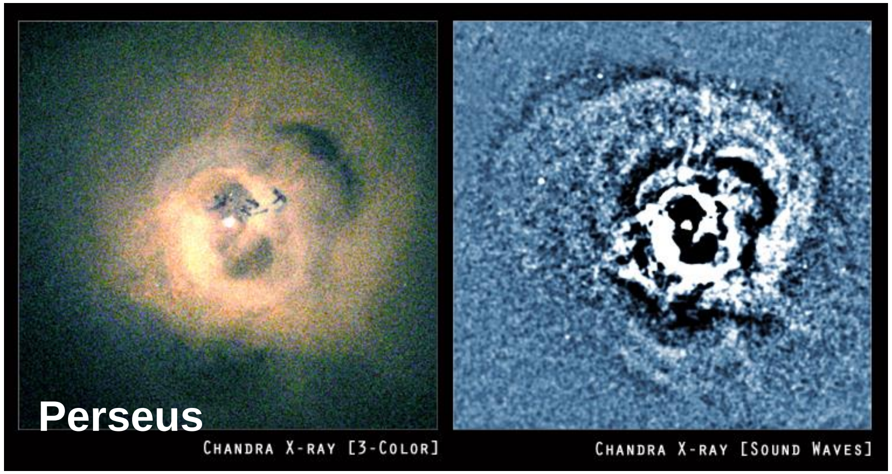
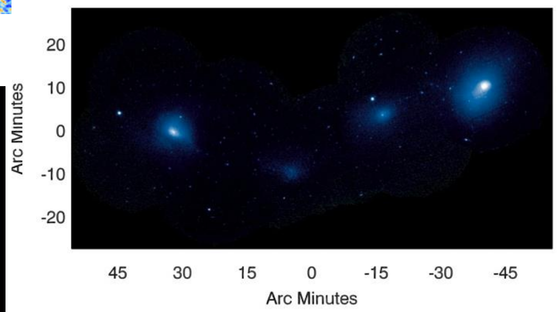
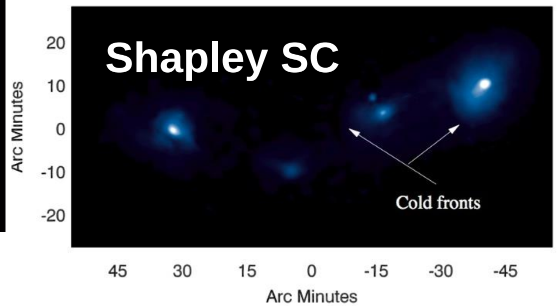
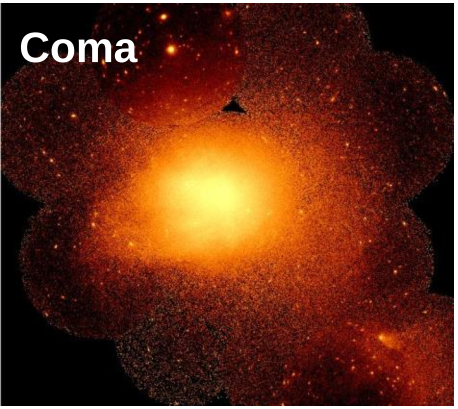
"One slide" overview of clusters of galaxies observed in the X-ray band

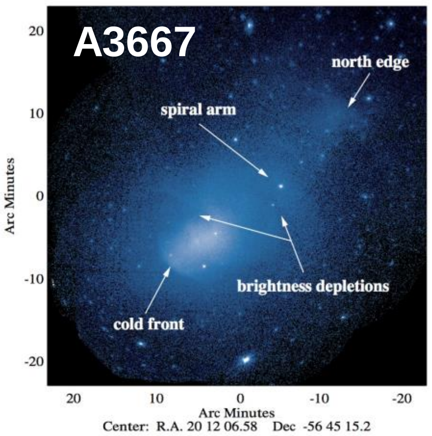


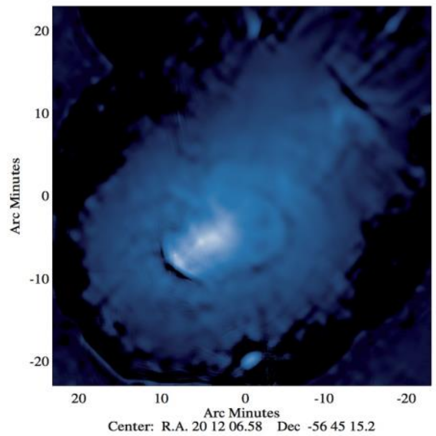


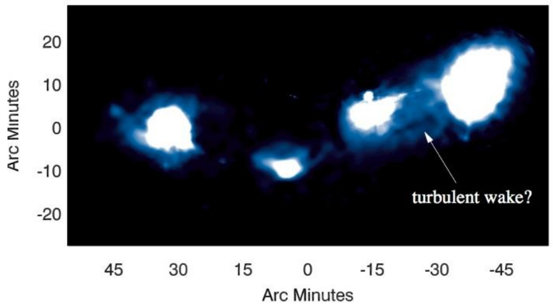


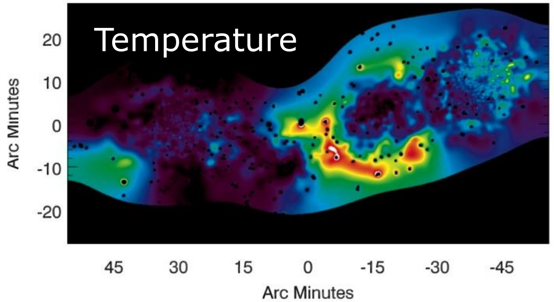




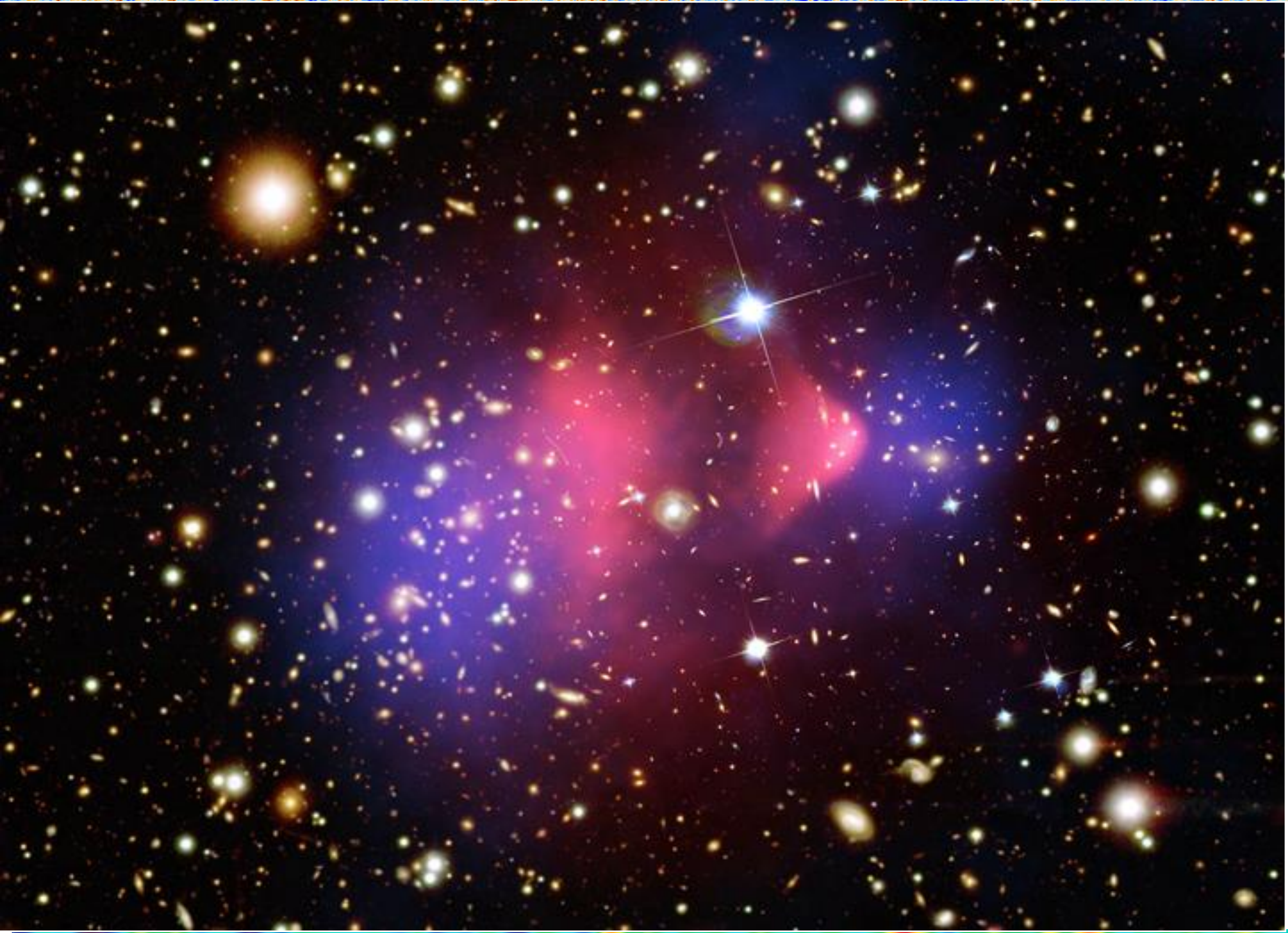








Direct evidence of the existence and "dominance" of Dark Matter

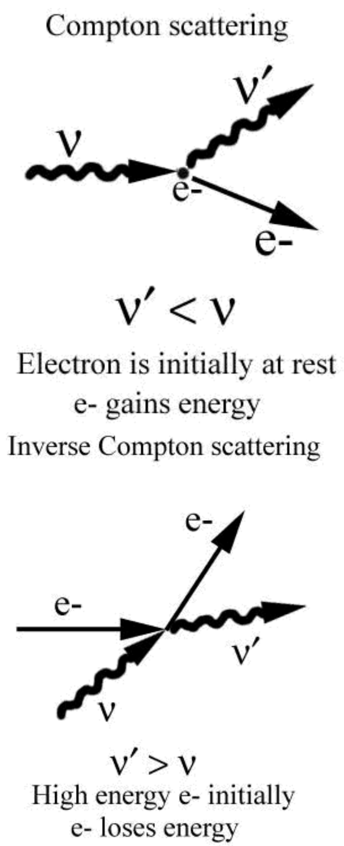


The Bullet Cluster

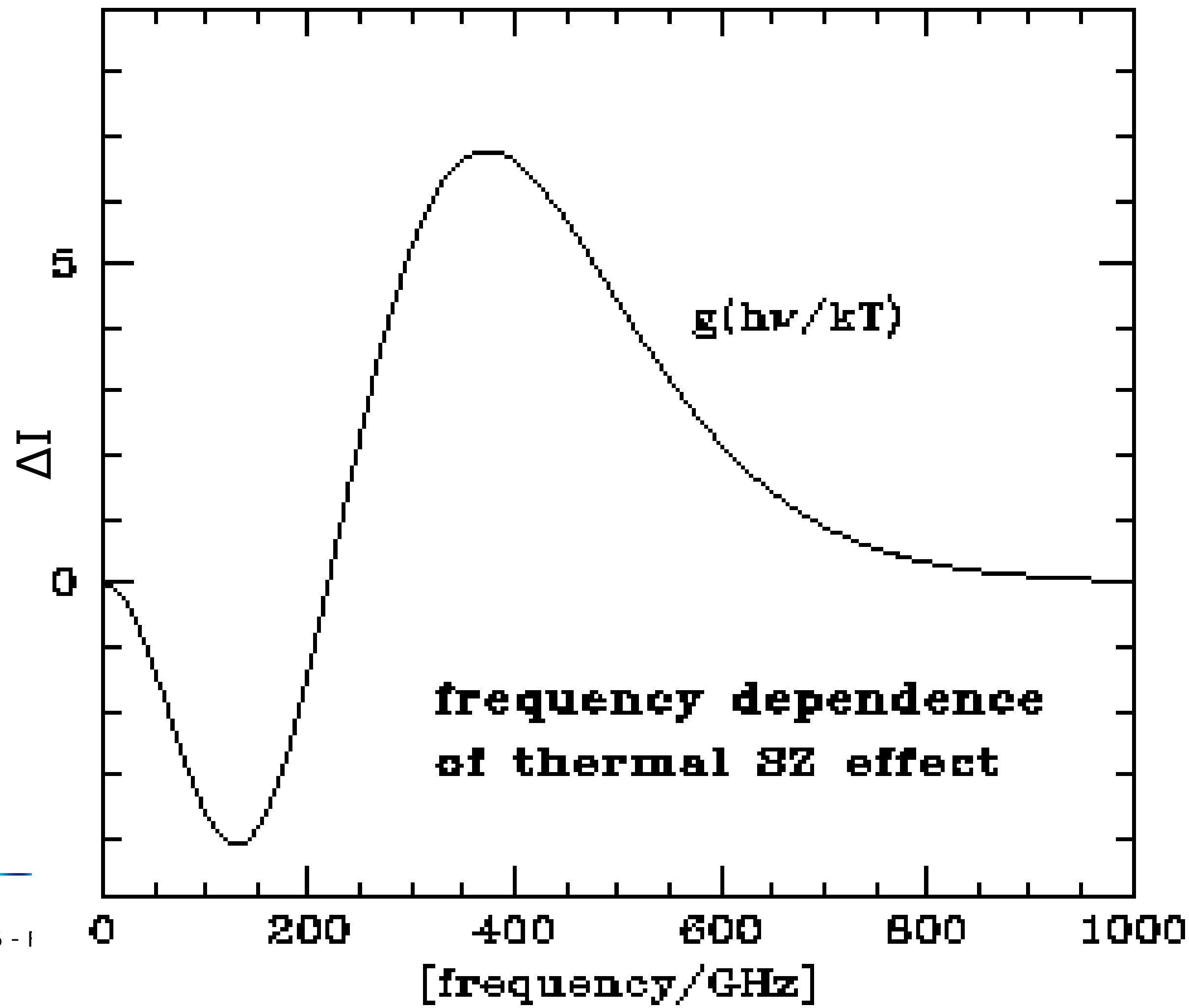
Markevitch et al. '04
Clowe et al '04, '07
Bradac et al. '07

Sunyaev Zel'dovich effect

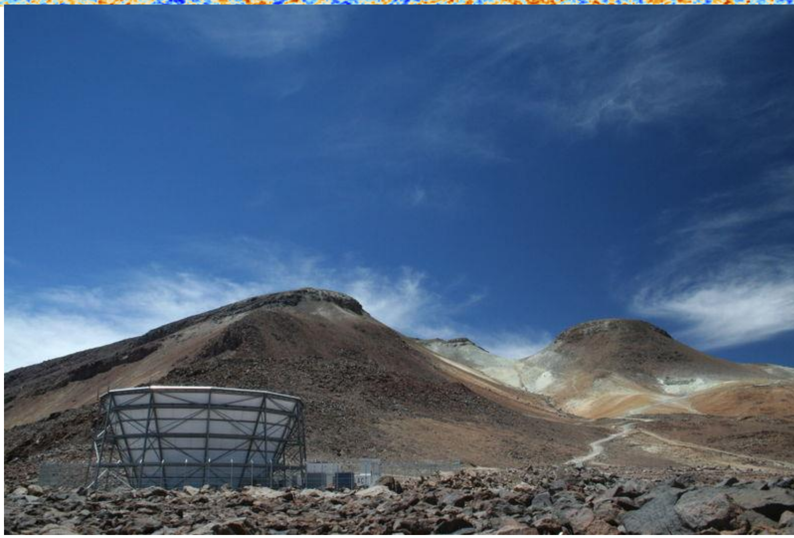
CMB+CLUSTERS



SZ effect (Sunyaev & Zel'dovich 1969)



Some Ground SZ telescopes



Atacama Cosmology Telescope

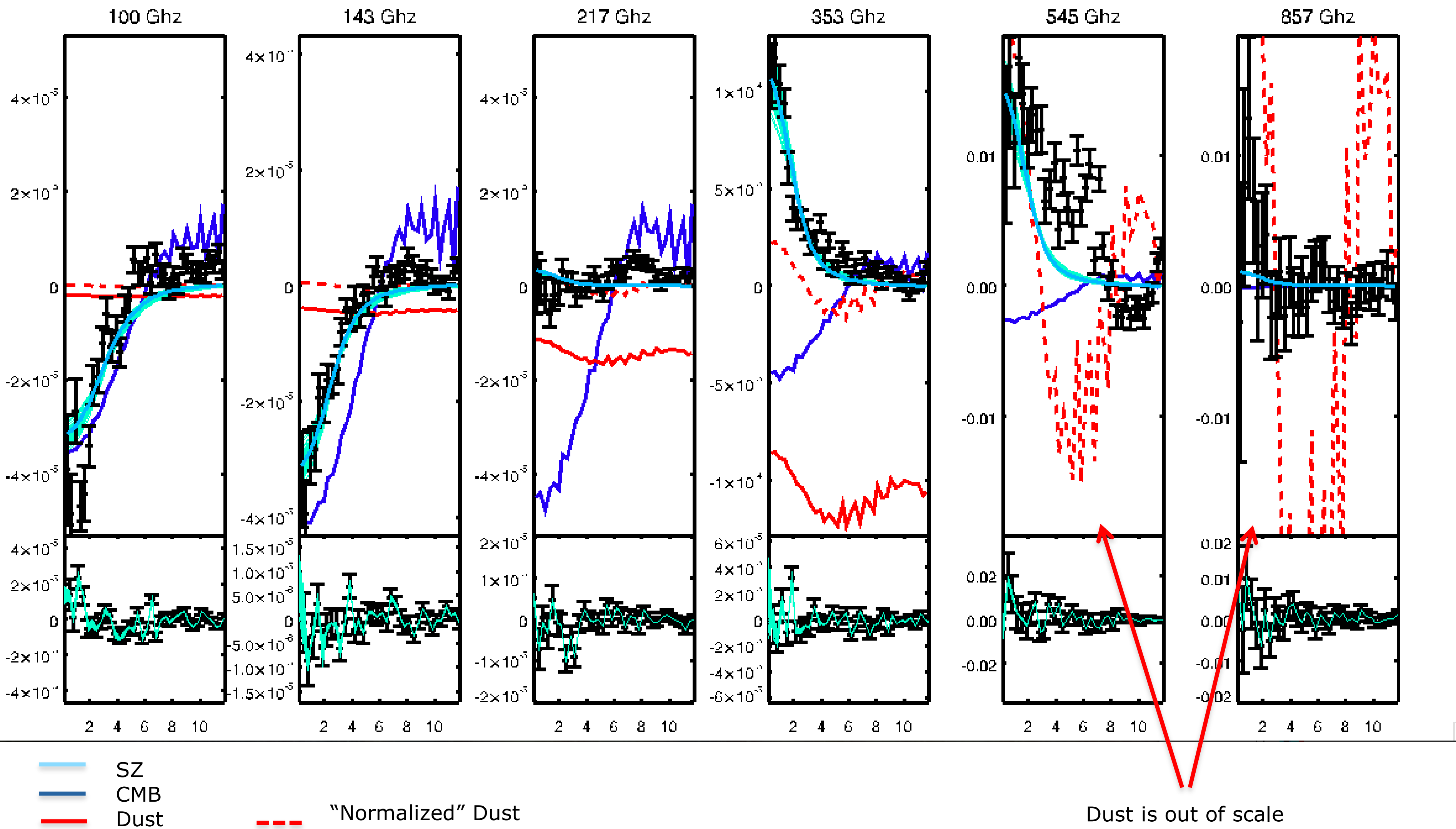
South Pole Telescope

AMI
AMiBA
APEX
SuZIE
MUSTANG

Sunyaev–Zel'dovich Array

Nika and Nika2

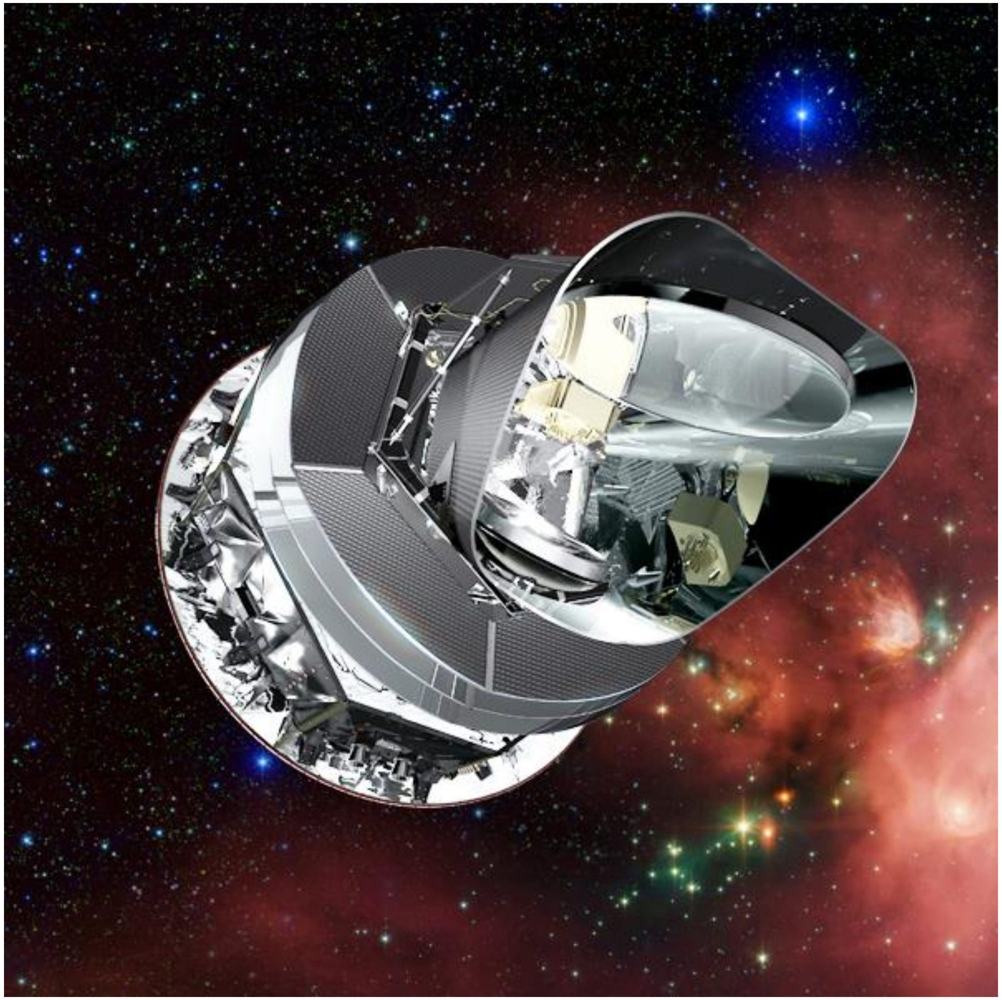
Accurate foreground separation requires High frequencies observations



Accurate foreground separation requires High frequencies observations!

This can be achieved only from space and (partially) from balloon-borne experiments

SZ observation from space: Planck



Pros:

- Larger frequency coverage: better foreground subtraction
- All sky survey: first all sky map of the SZ signal

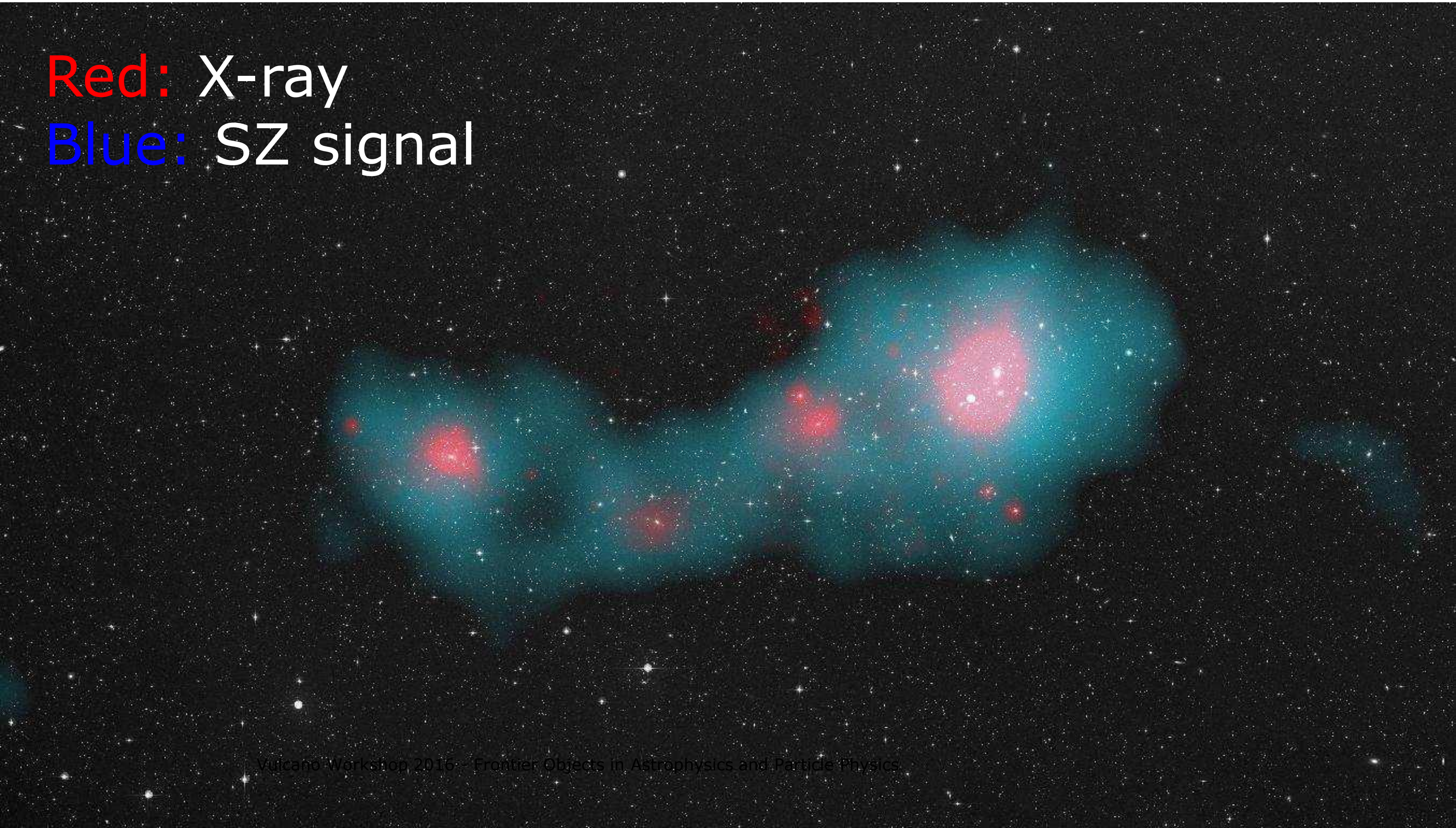
Cons:

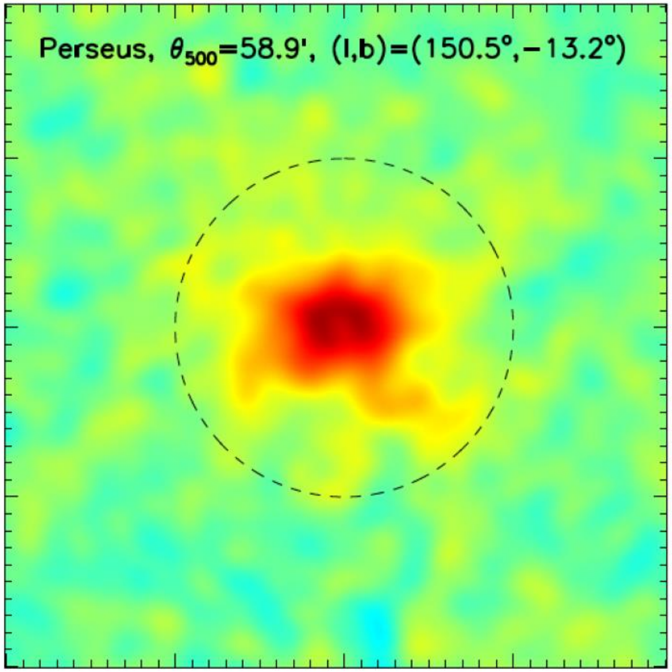
- Lower angular resolution and lower exposure time per clusters: impossibility to detect clusters at z>1

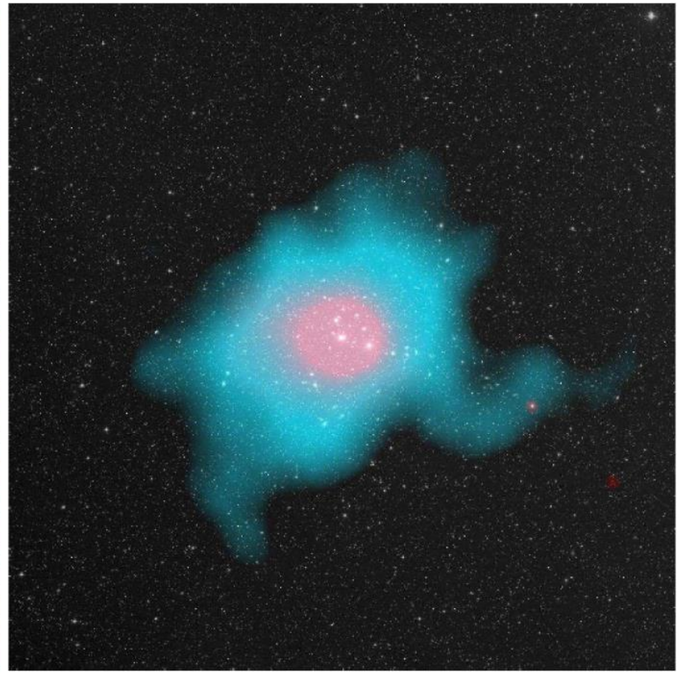
Some nice pictures

Shapley supercluster: SZ observation of hot gas in filaments

Planck 2013. XXIX, A&A

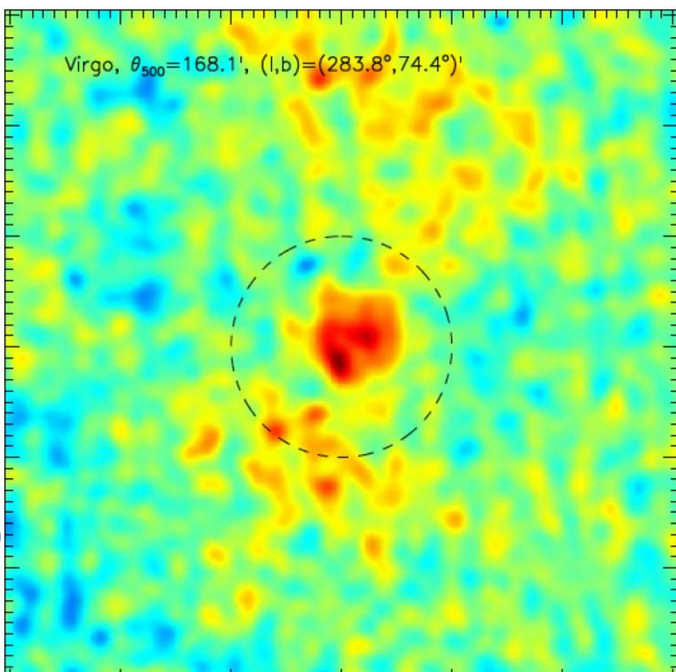


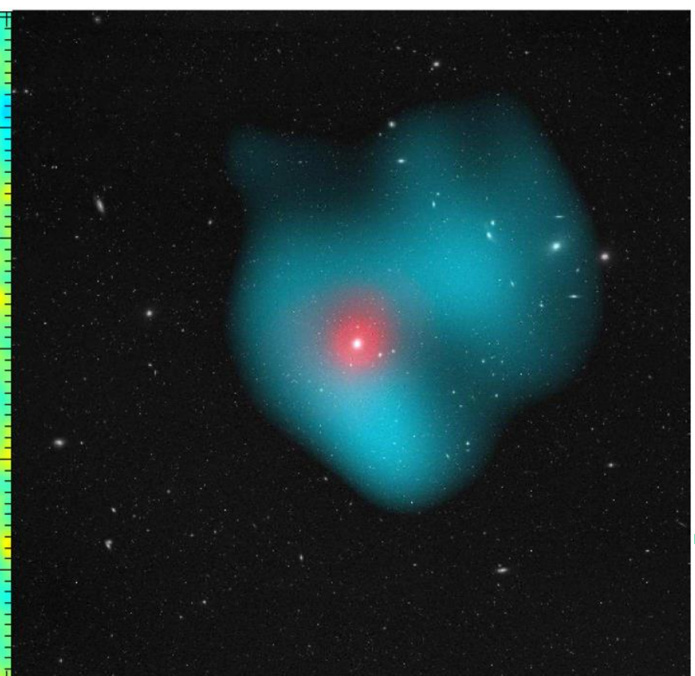




Planck 2013. XXIX, A&A

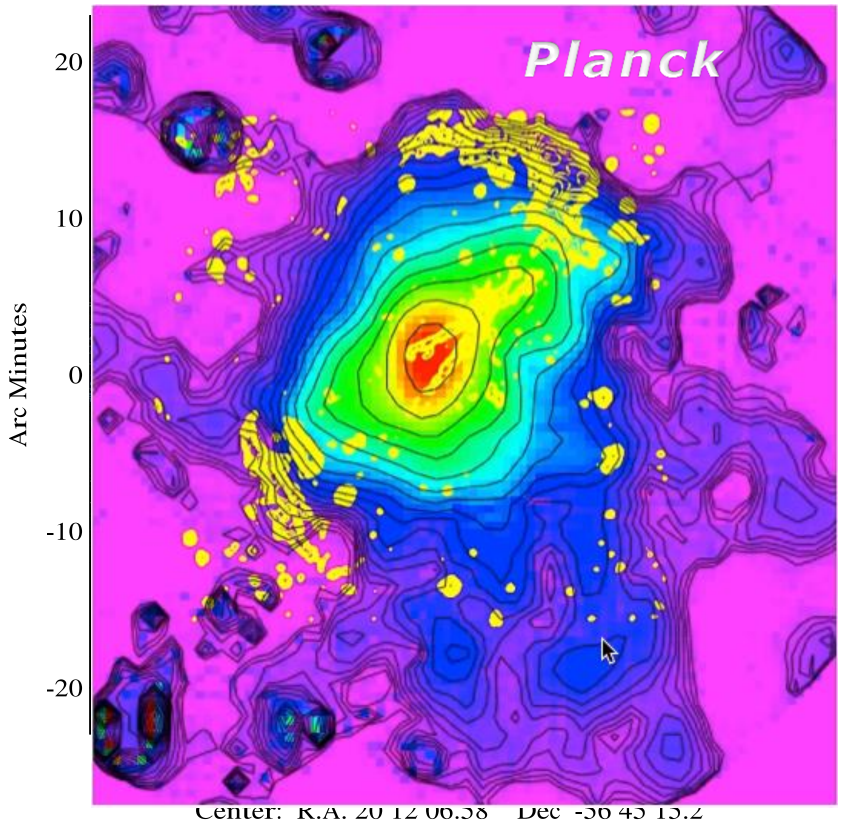
2x2 deg

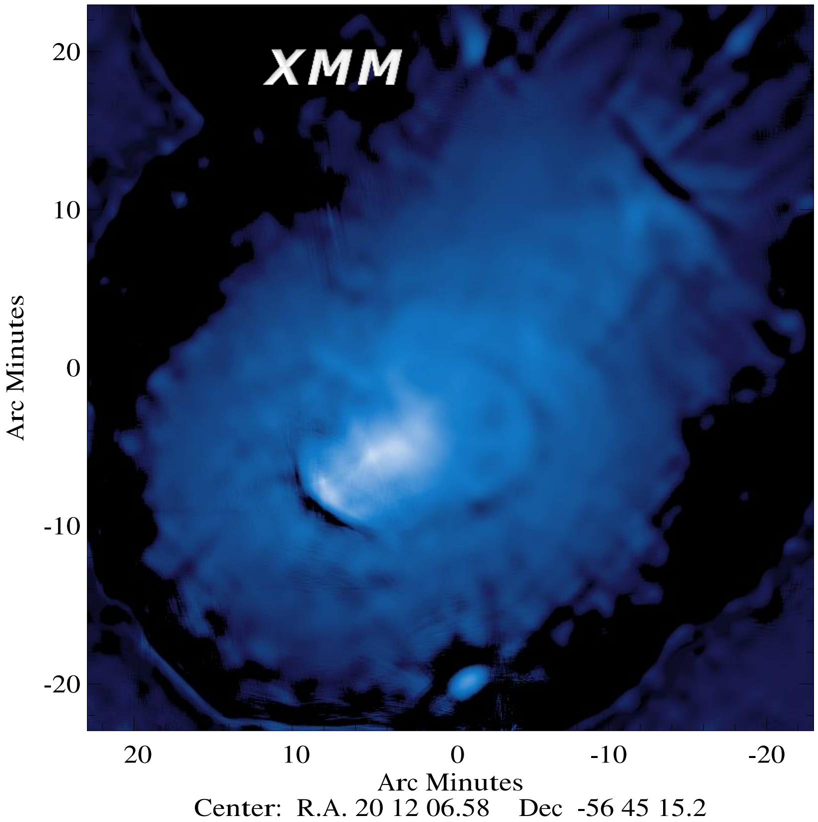




3.84x3.84 deg

Planck image and XMM mosaic of A3667

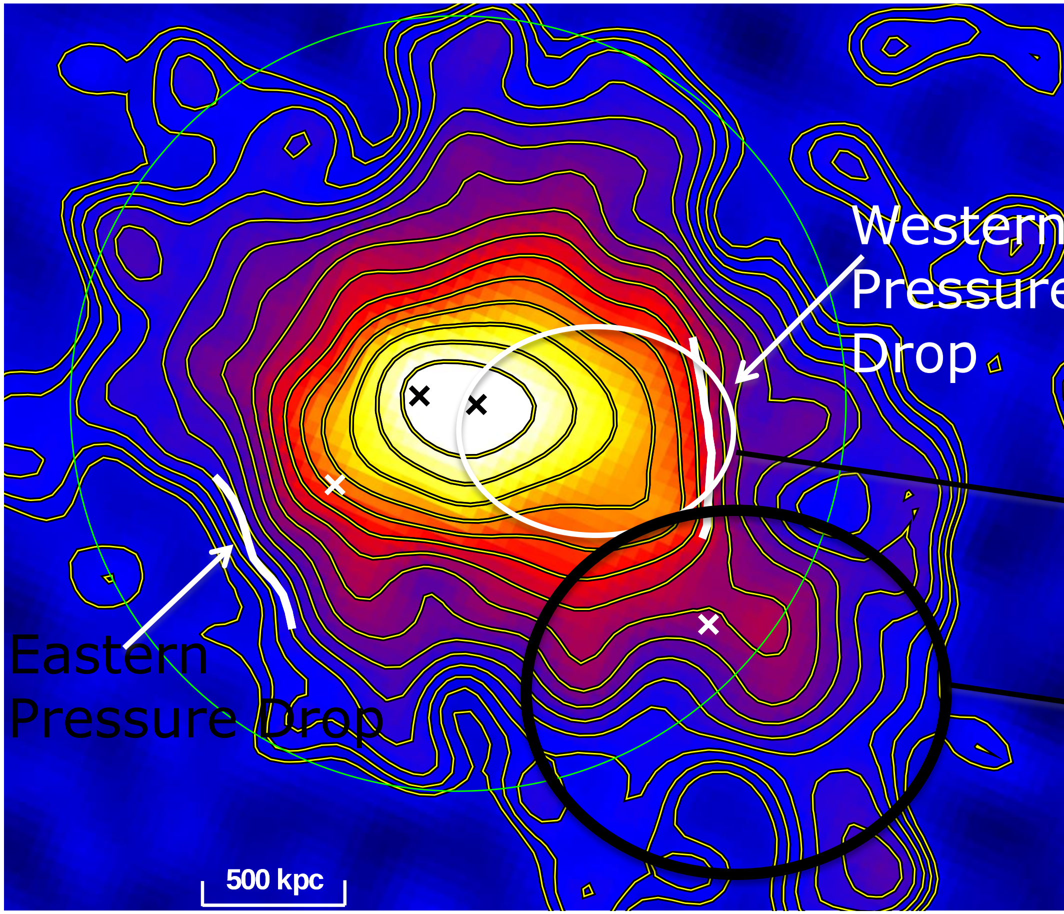




Yellow isocontours: radio relics
Black isocontours: SZ signal

XMM Mosaic and Planck SZ image from Bourdin, P.M.

Planck y Map of Coma



Planck IR. X, A&A

MILCA 10 arcmin
Levels> 2*σ
σ= 2.13x10^{-6}
Levels log equispaced by 2$^{1/4}$
Green circle = R$_{500}$

HFI from 100 GHz to 857 Ghz

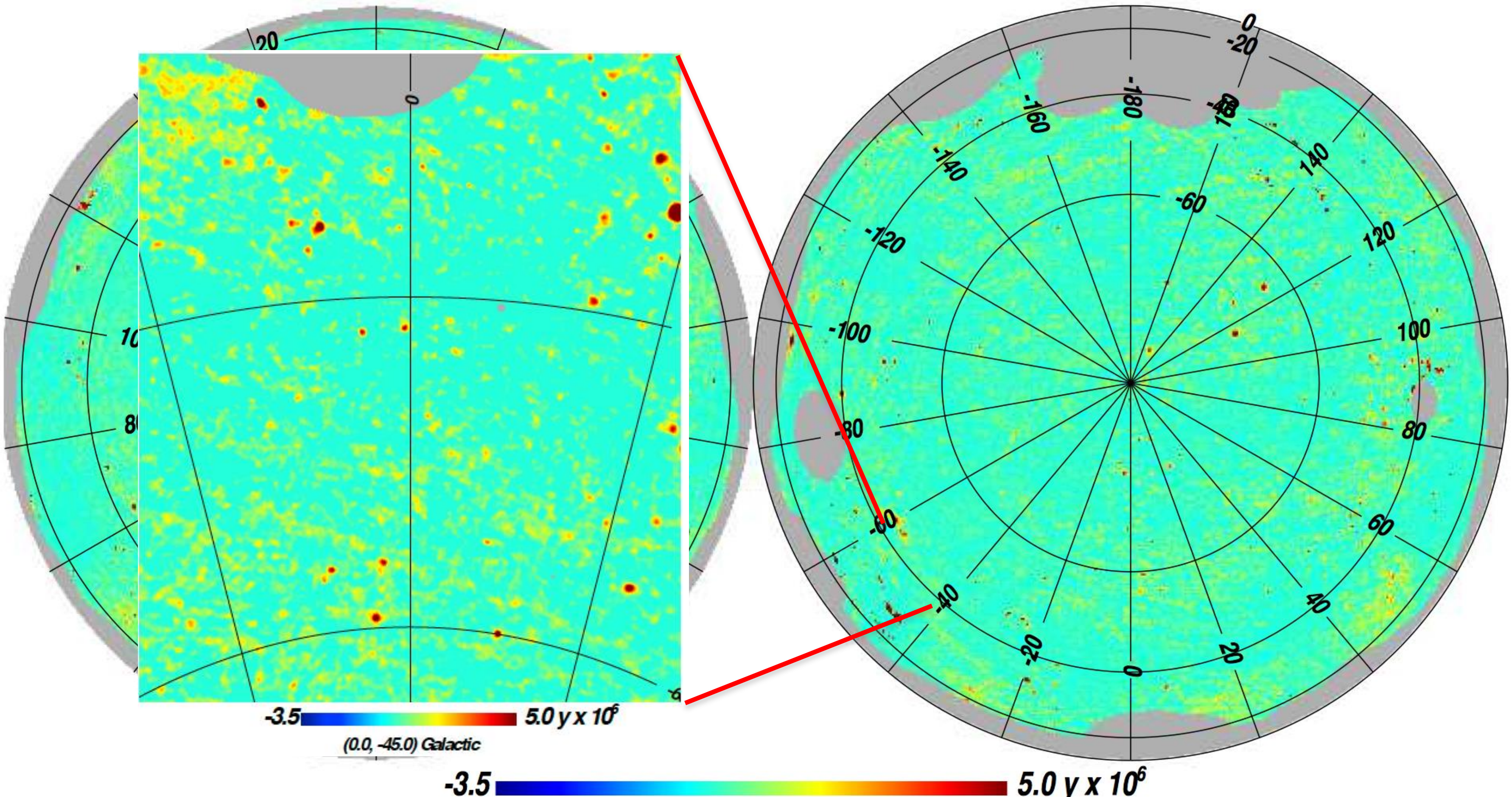
Y map extended in the East-West direction

extended Y emission

Planck Map of the Thermal SZ

First All-sky map of the diffuse SZ signal

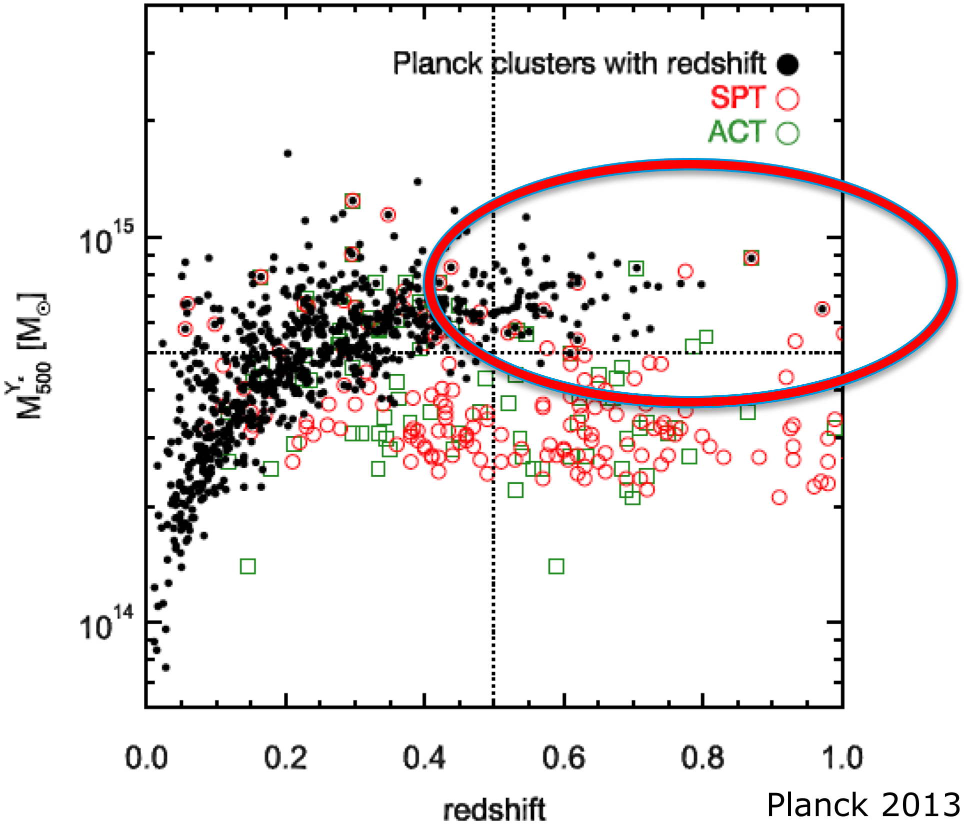
This can be achieved only from space as we need high frequencies to properly model and remove foreground and background components

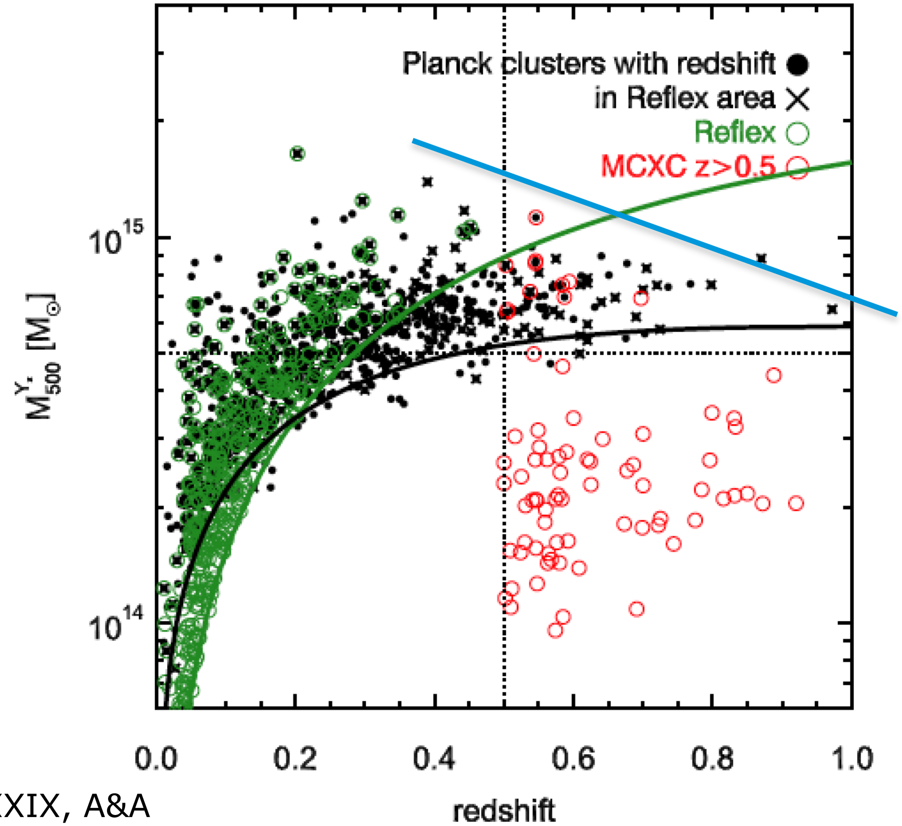


Planck 2015 XXII, A&A

redshift distribution

Space all-sky SZ survey allows to access region of the mass-redshift plot
That are inaccessible to current ground experiments

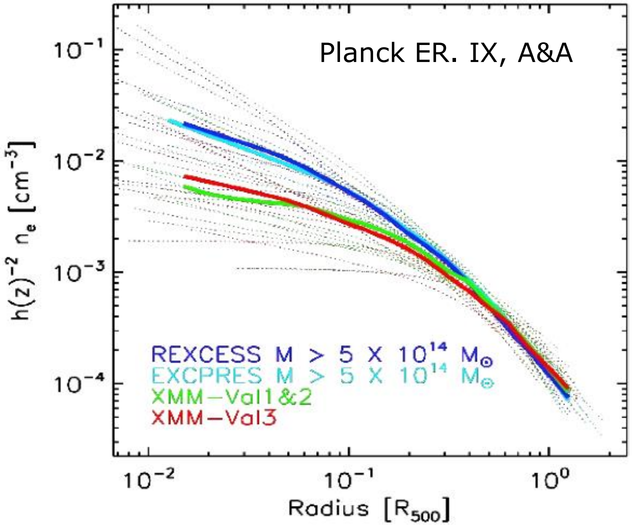




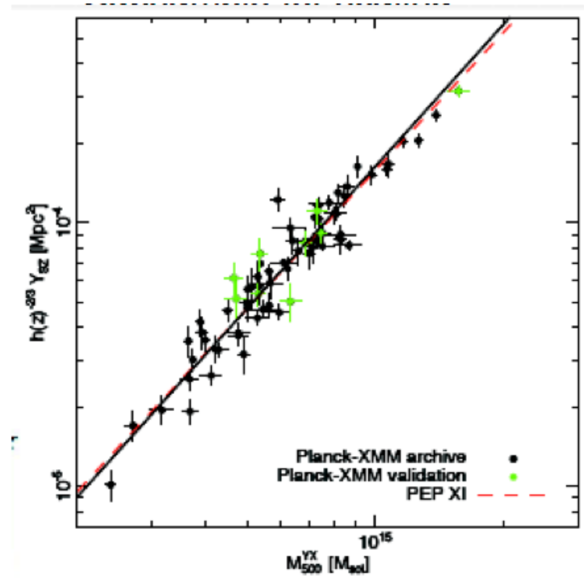
Planck 2013. XXIX, A&A

Joint analysis of Planck SZ data with other data sets

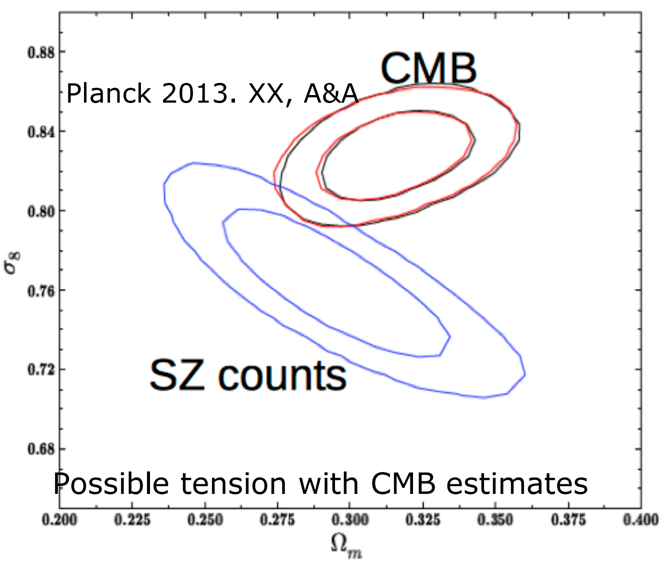
X-ray profiles of a SZ selected population



Y_{sz}-Y_x Relation

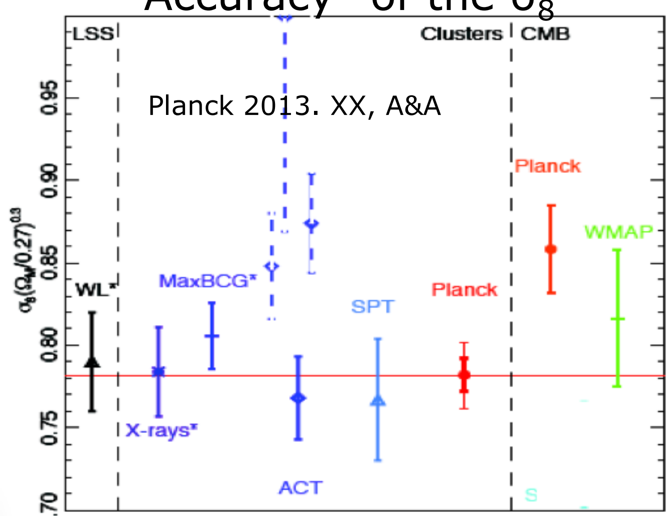


Estimates of Ω_m-σ_8

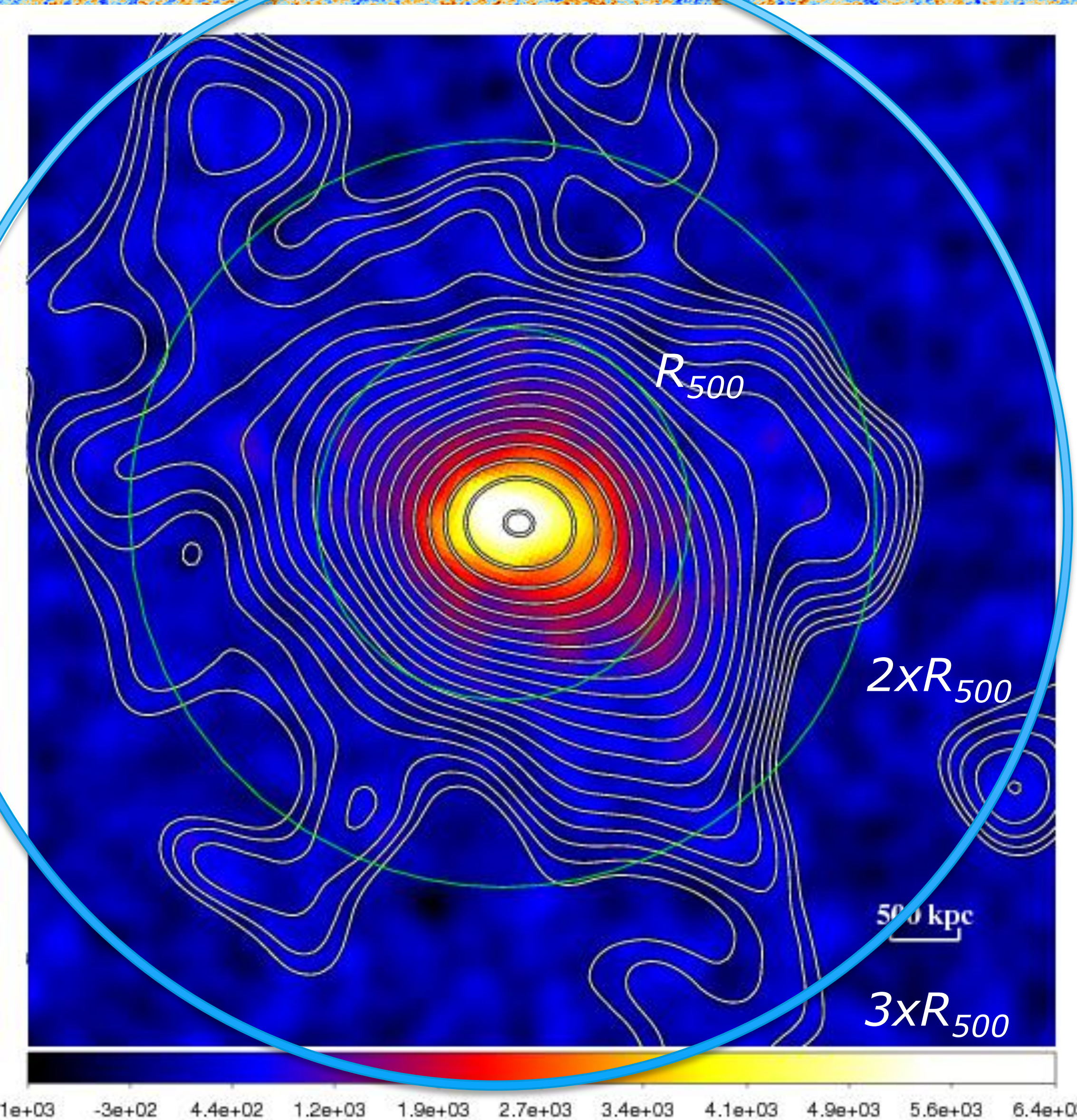


Possible tension with CMB estimates

"Accuracy" of the σ_8

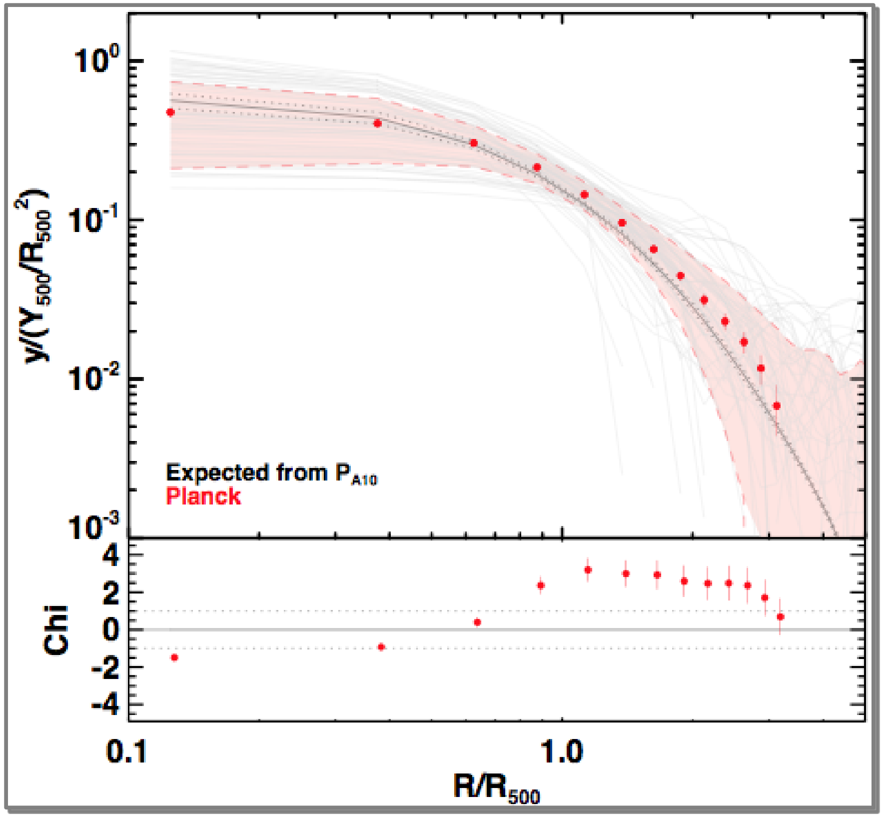


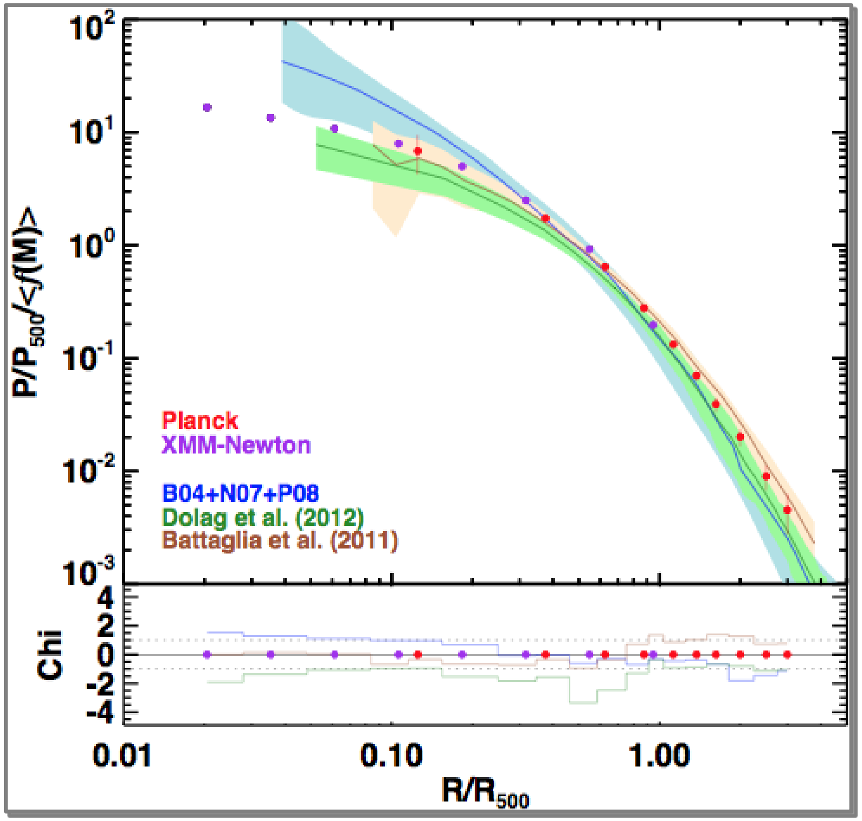
Probing the clusters outskirts



1. Current X-ray telescope sensitivity allow us to detect X-ray emission up to R_{500}
2. (With some work) Planck SZ map allow us to map the gas distribution of to R_{200}=2 R_{500}
3. If we extract radial profiles we can detect signal up to $3\ R_{500}$ or more

Pressure profiles of 60 nearby clusters (z<0.5) observed with Planck and XMM-Newton



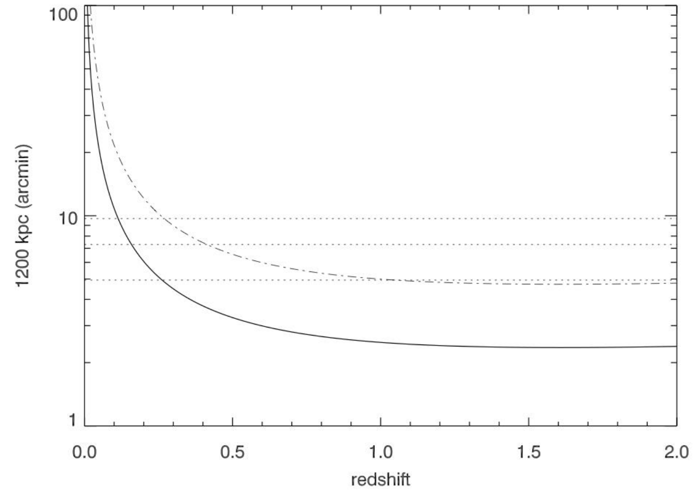


Planck collaboration. 2013

The Problem/Goal and the new Solution/Method

G: Estimate with Planck the pressure profile of clust at z>0.5 up to $3xR_{500}$

P: These clusters have Θ_{500} <9.69′ but the instrument angular resolution depend on the frequency and ranges from 10′ at 100GHz to 4.64′ at 857GHz



S: To use the observed frequency maps to the highest angular resolution available (as opposite to smooth all the maps to the lowest to perform interlinear combinations)

M: Our new method uses the frequency maps as independent channels that we use to fit the different components and retrieve an accurate component separation

Extended component mixing

Frequency maps → $I = As + N$

- Emitting sources
- Instrumental noise
- Mixing matrix

1.For ν >100 Ghz:

$$I(k,l,\nu) = R(\nu) \times \left[A_{SZ}(k,l)\, f_{SZ}(\nu) \right.$$
$$+ A_{dust}(k,l)\, f_{dust}(\nu)$$
$$\left. + A_{CMB}(k,l) \right]$$

Preliminary results on Pressure profile of cluster observed with Chandra XMM and Planck at z>0.5

- *Planck Compton parameter*
  --> Gas pressure (Nagai, Kravtsov & Vikhlinin, 07):

$$P_{500} = 1.45 \times 10^{-12} J.m^{-3} \left(\frac{M_{500}}{10^{15} h^{-1} M_{\odot}^{2/3}} \right) E(z)^{8/3}$$

$$\frac{P(r)}{P_{500}} = \frac{P_0}{x^{\gamma} (1+x^{\alpha})^{(\beta-\alpha)/\alpha}}$$

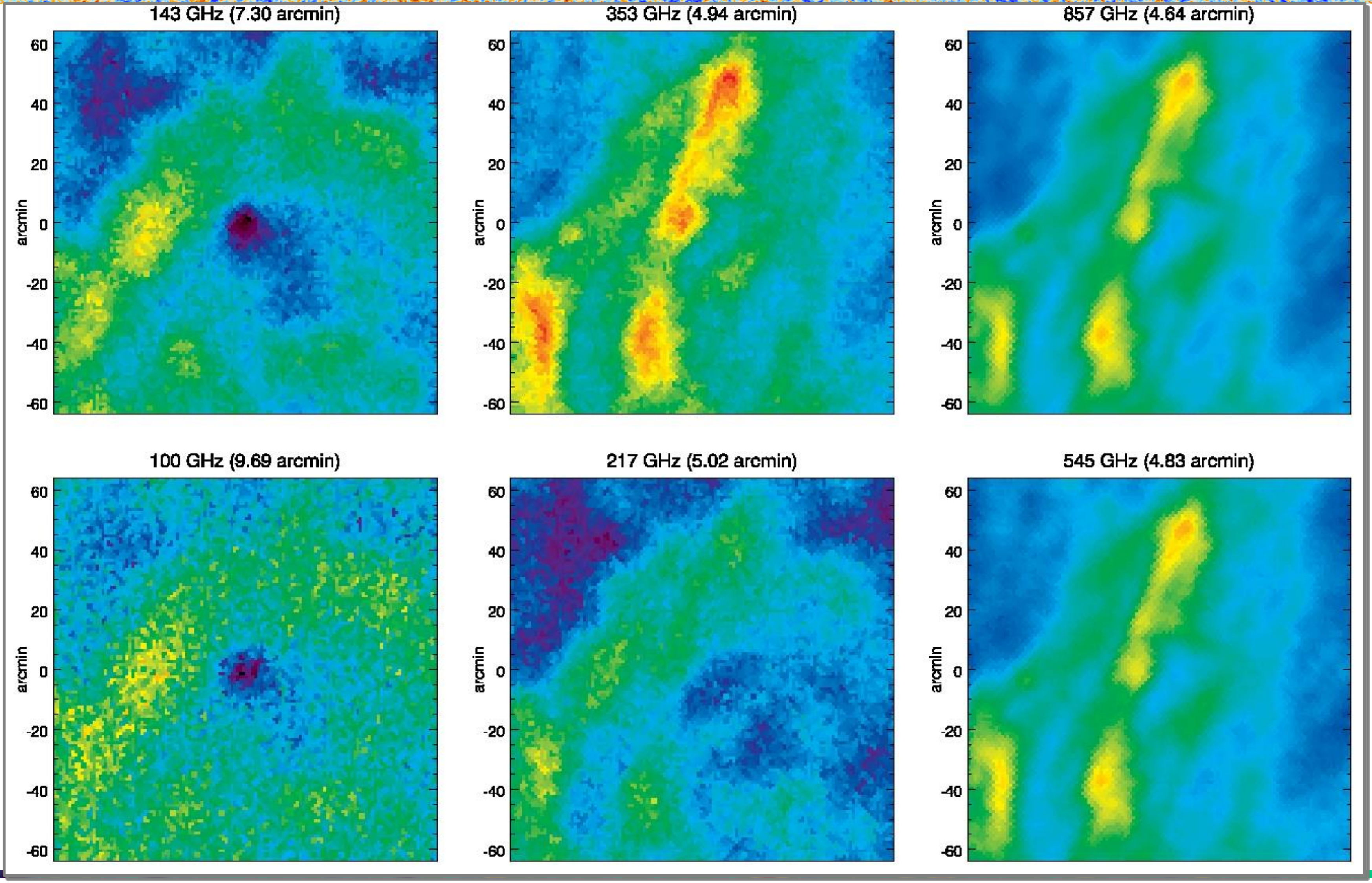
- *X-ray surface brightness ($r<r_{x,max}$)*
  --> Gas density (Vikhlinin et al., 06):

$$n_p n_e = n_o^2 \frac{(r/r_c)^{-\alpha}}{(1+r^2/r_c^2)^{(3\beta-\alpha/2)}} \frac{1}{(1+r^{\gamma}/r_s^{\gamma})^{\epsilon/\gamma}} + \frac{n_{o2}^2}{(1+r^2/r_{c2}^2)^{3\beta_2}}$$

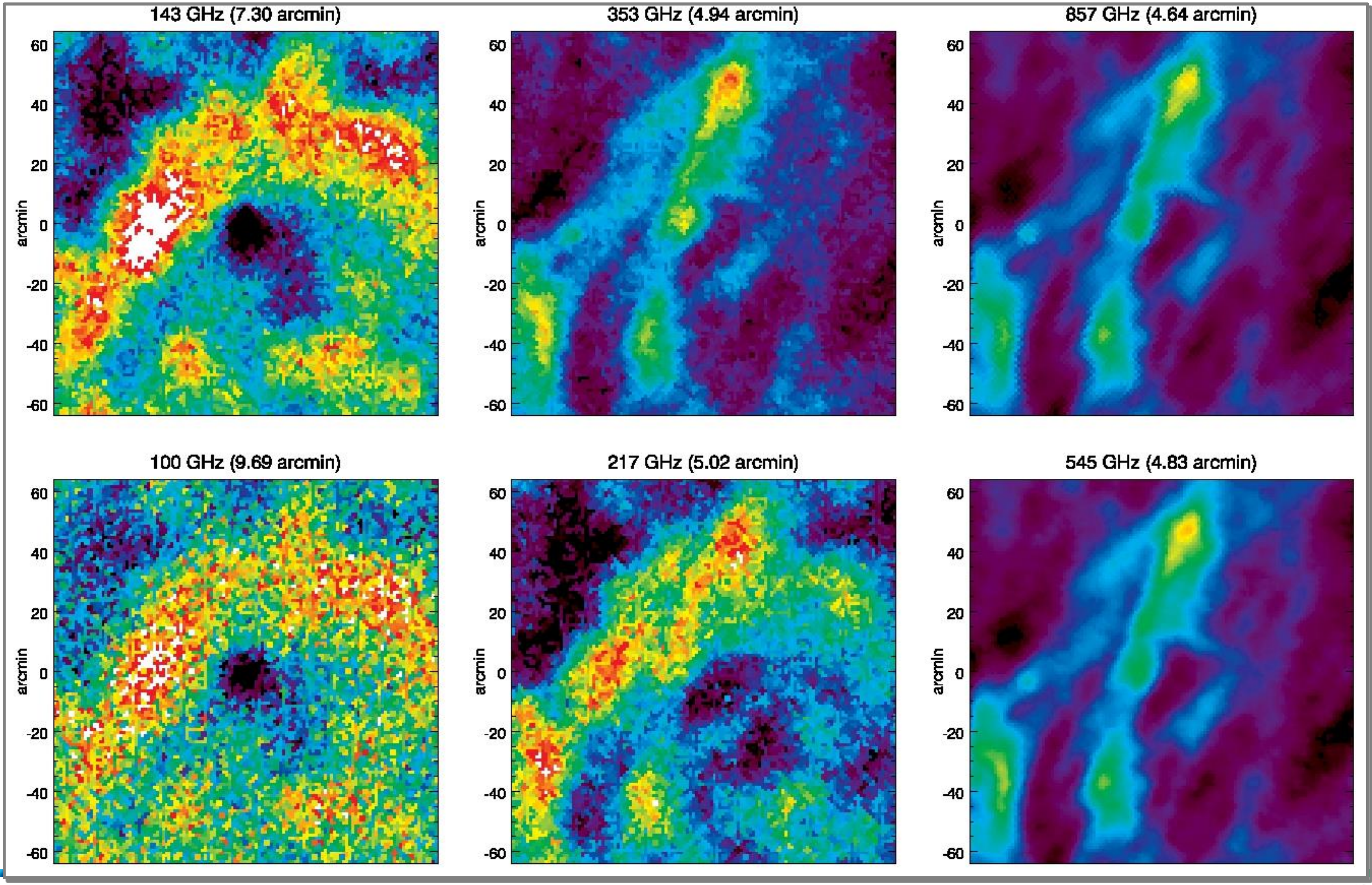
- *Planck Compon parameter + X-ray spectroscopic temperature ($r<r_{x,max}$)*
  --> Ideal gas temperature

$$T(r) = T_o \frac{P(r)}{n_e(r)}$$

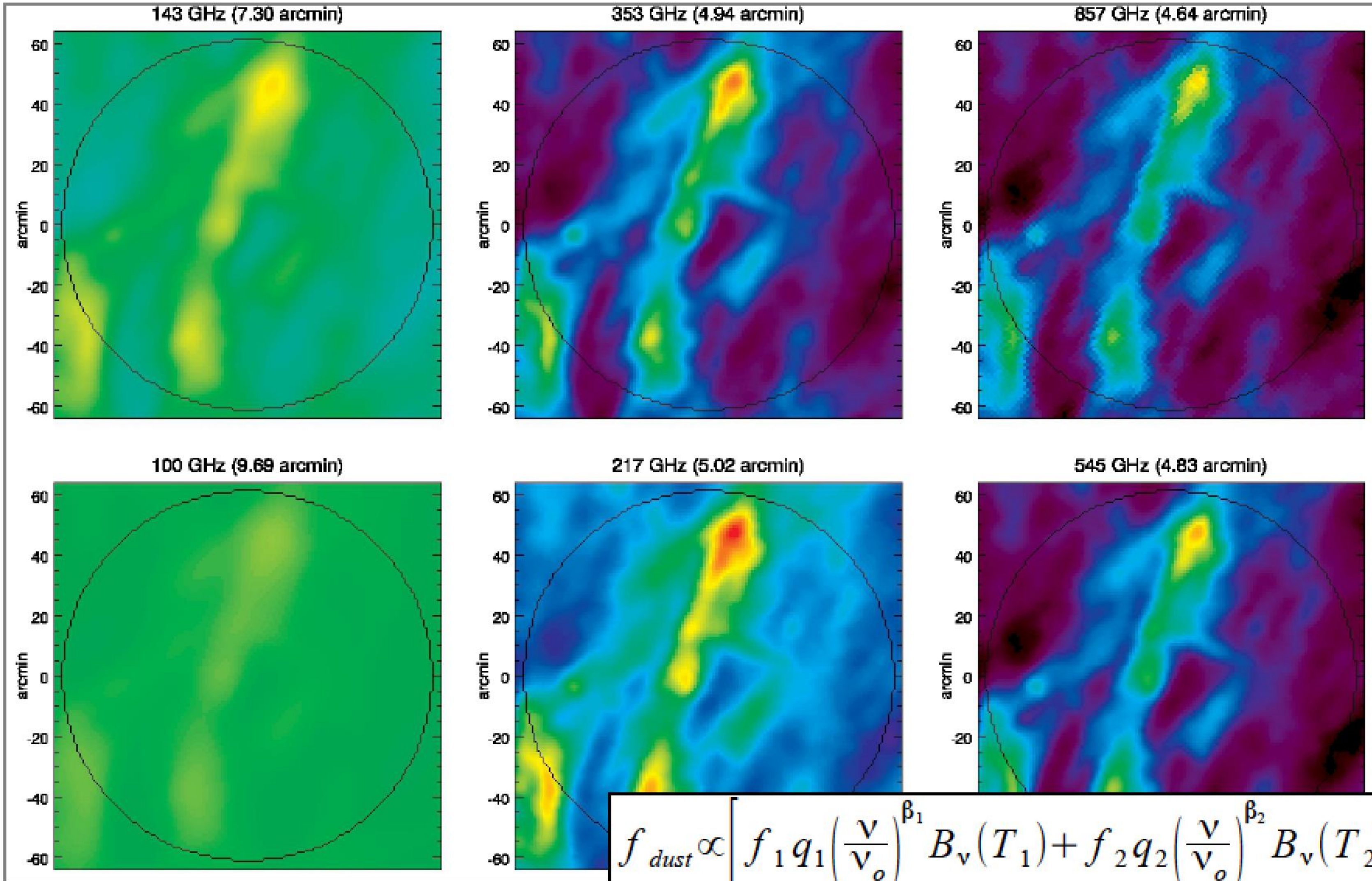
HFI images of Abell 2163



1/5) High-pass filtering

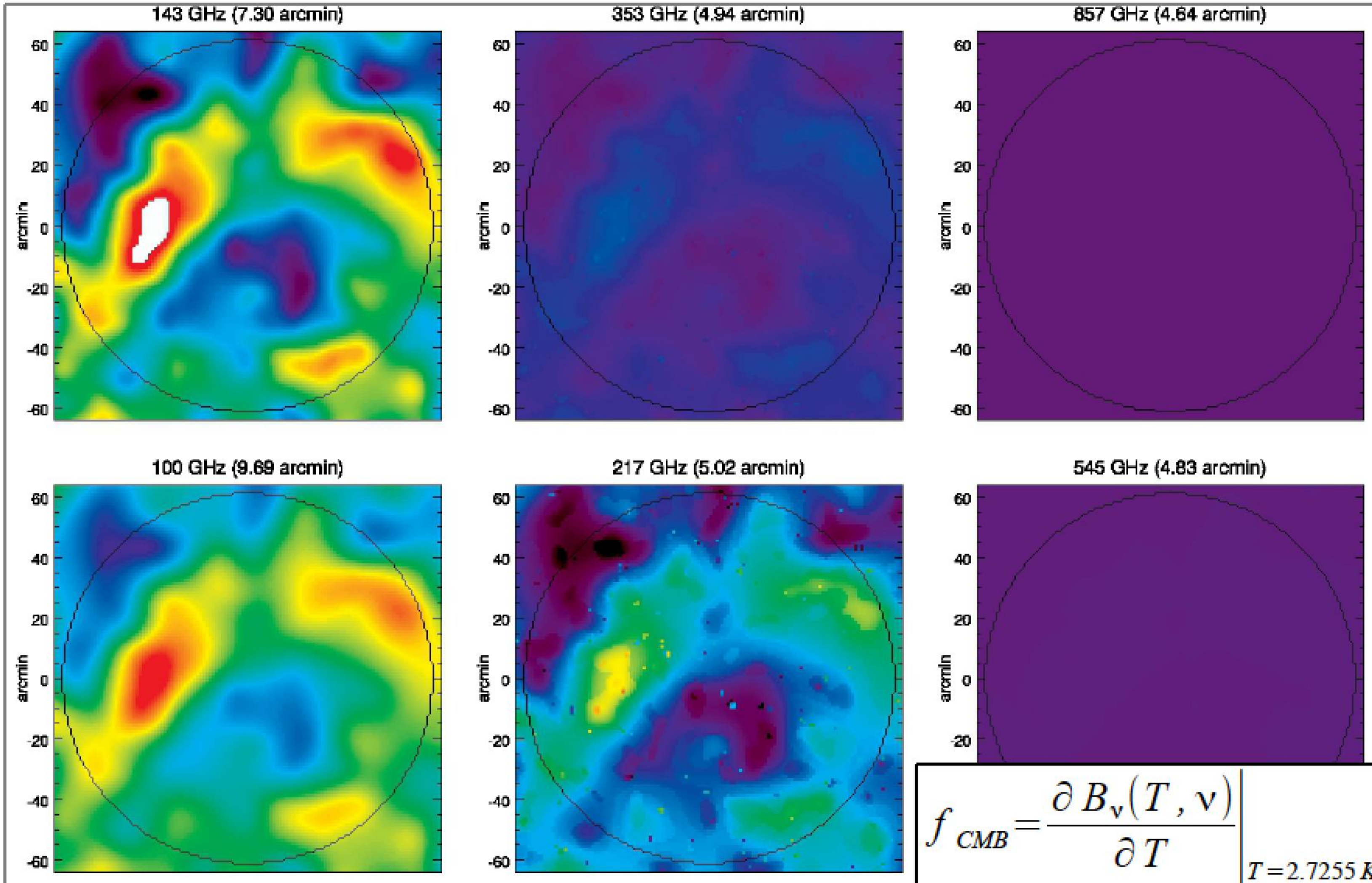


2/5) Thermal dust modelling / subtraction



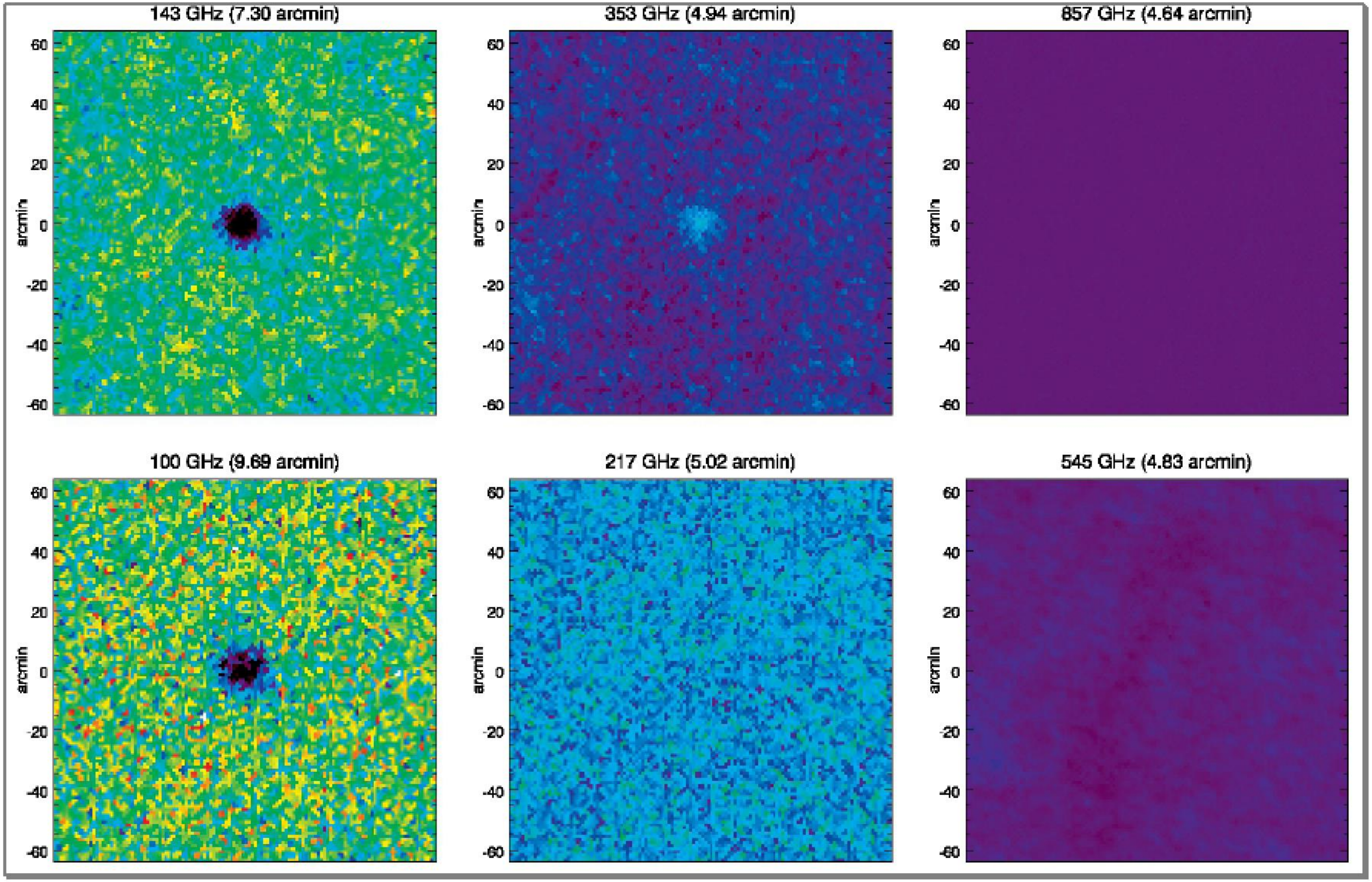
$$f_{dust} \propto \left[f_1 q_1 \left(\frac{\nu}{\nu_o}\right)^{\beta_1} B_\nu(T_1) + f_2 q_2 \left(\frac{\nu}{\nu_o}\right)^{\beta_2} B_\nu(T_2) \right]$$

3/5) CMB modelling / subtraction

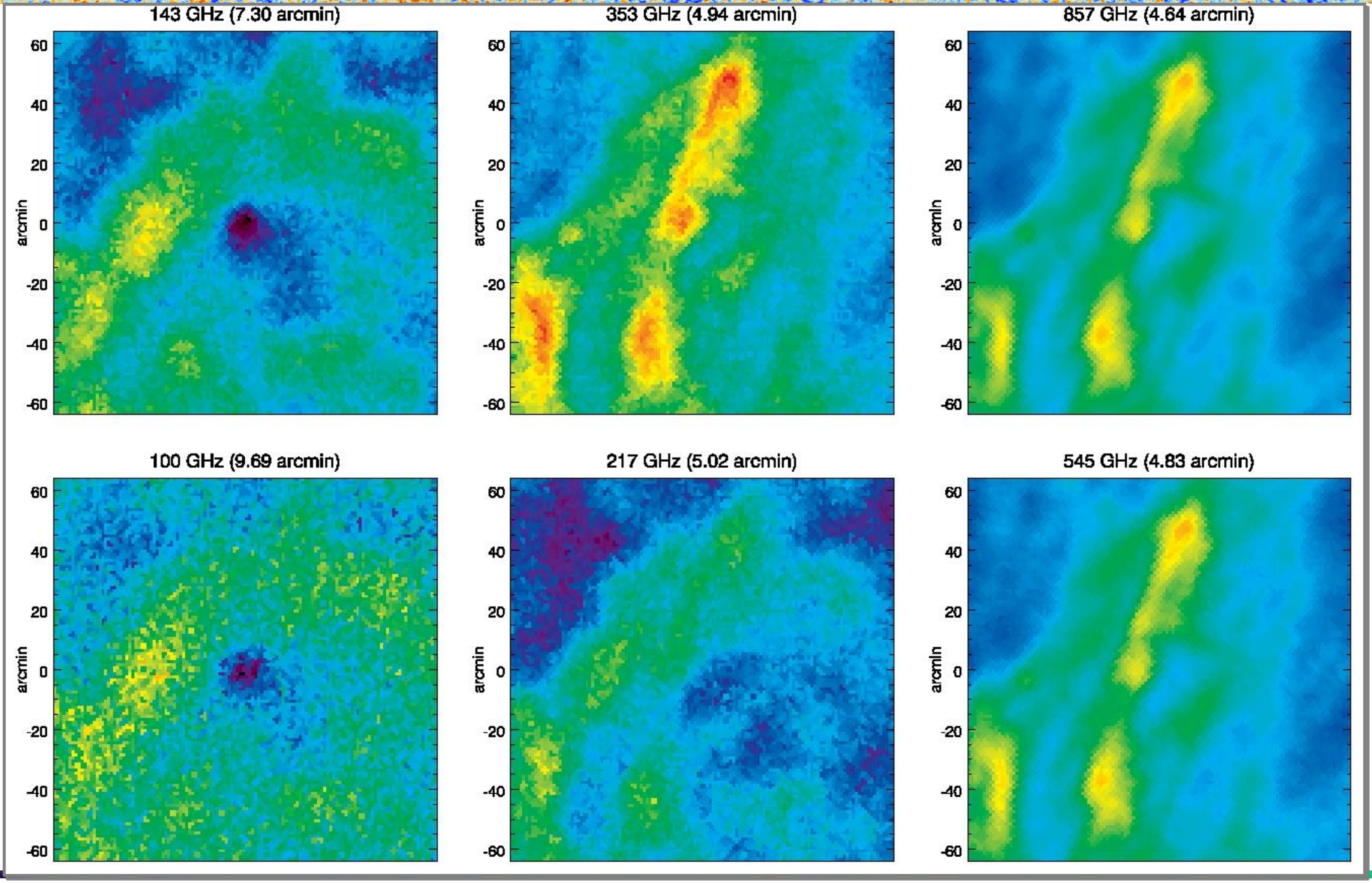


$$f_{CMB} = \left. \frac{\partial B_\nu(T,\nu)}{\partial T} \right|_{T=2.7255\,K}$$

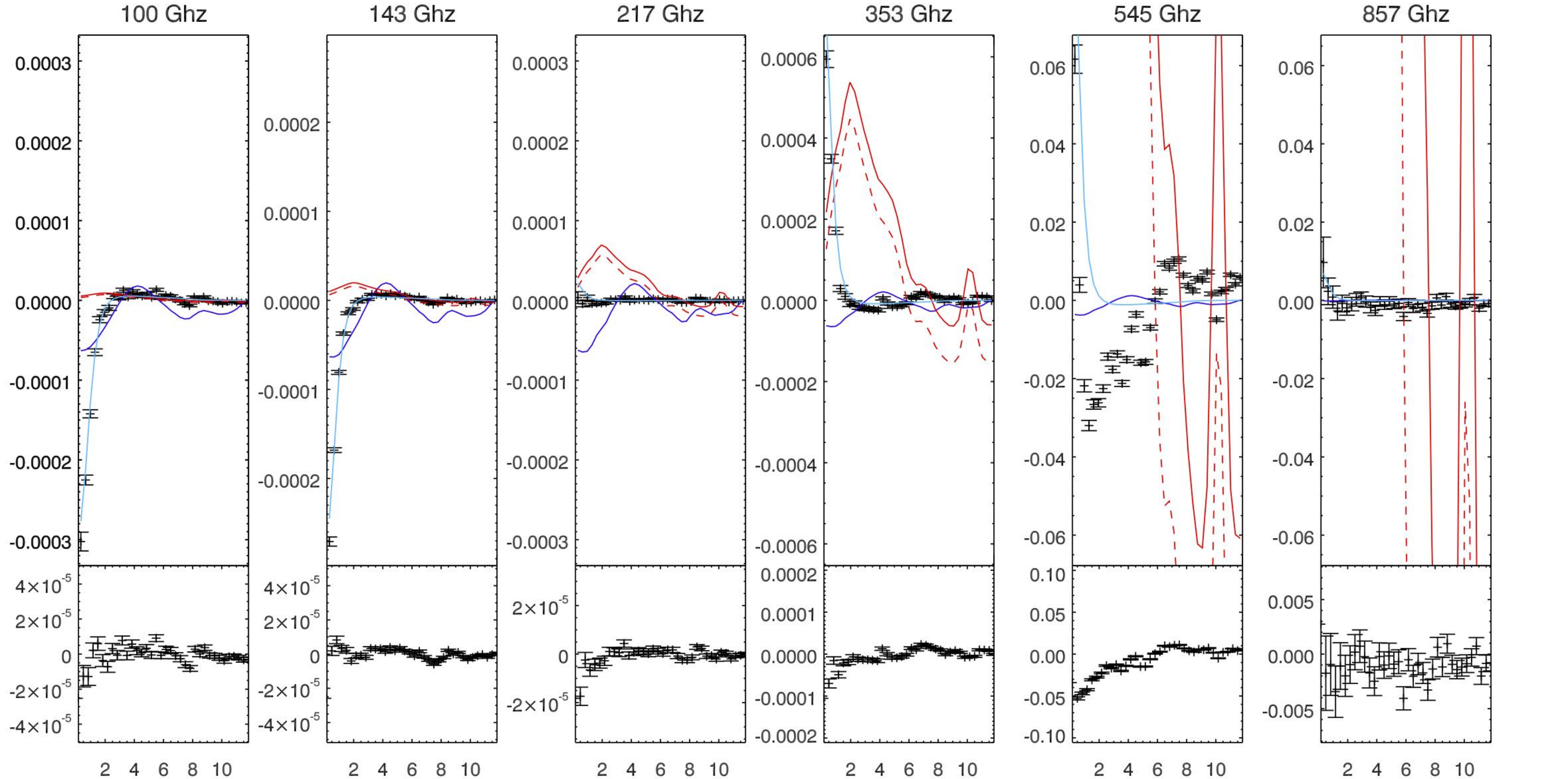
4/5) High (spatial) frequencies residua



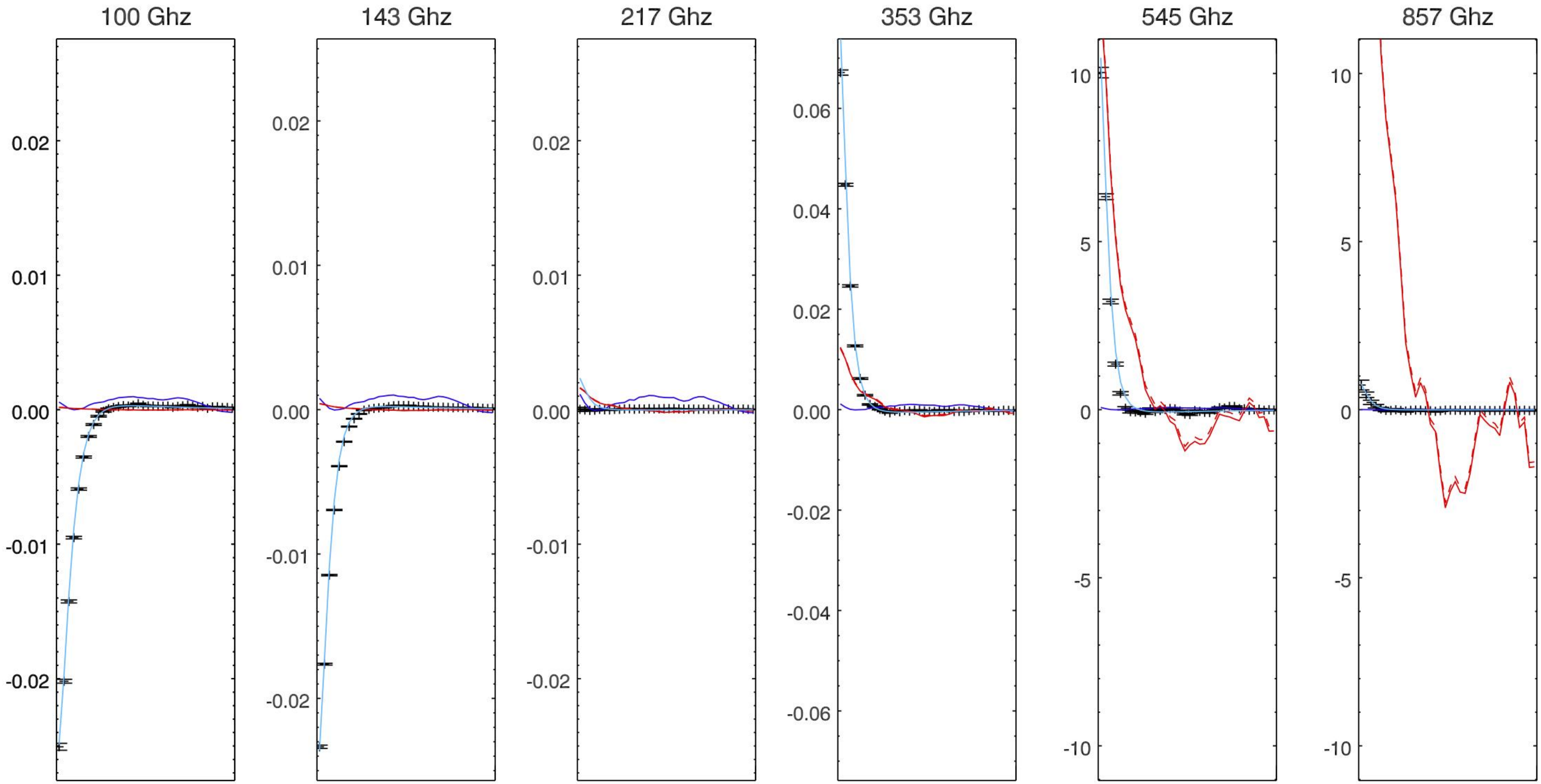
HFI images of Abell 2163: where we started from!



5/5) Cluster template fitting

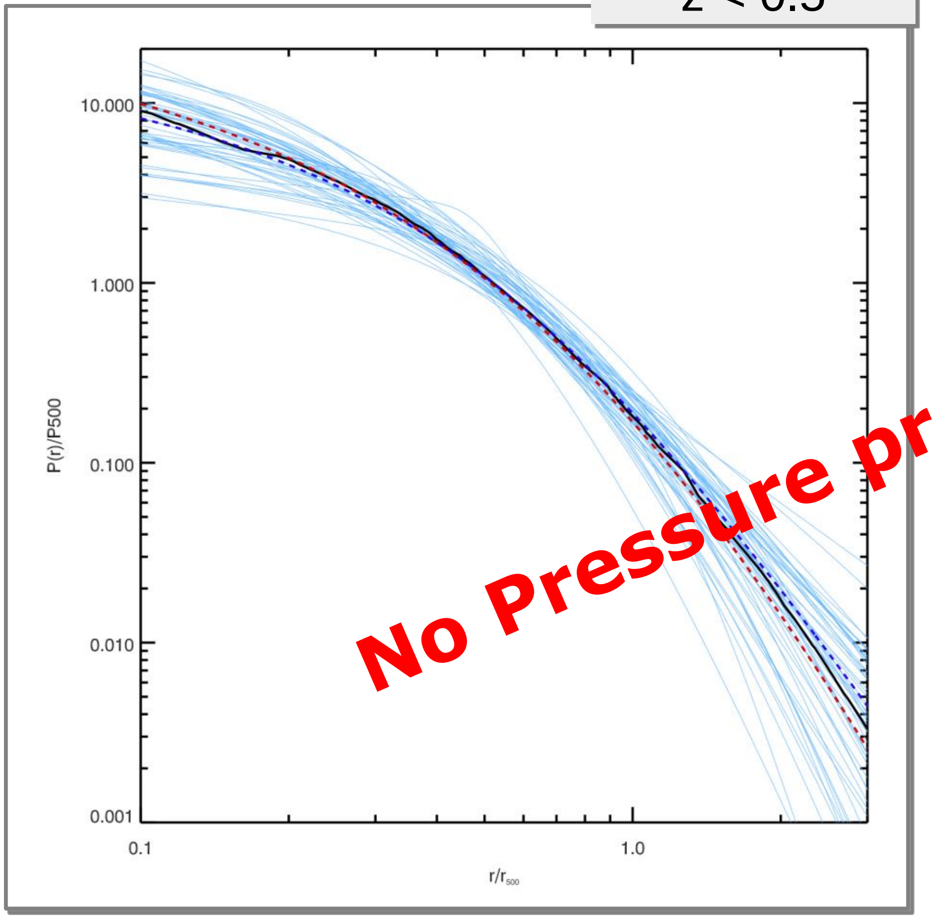


Stacked Planck cosmology cluster sample

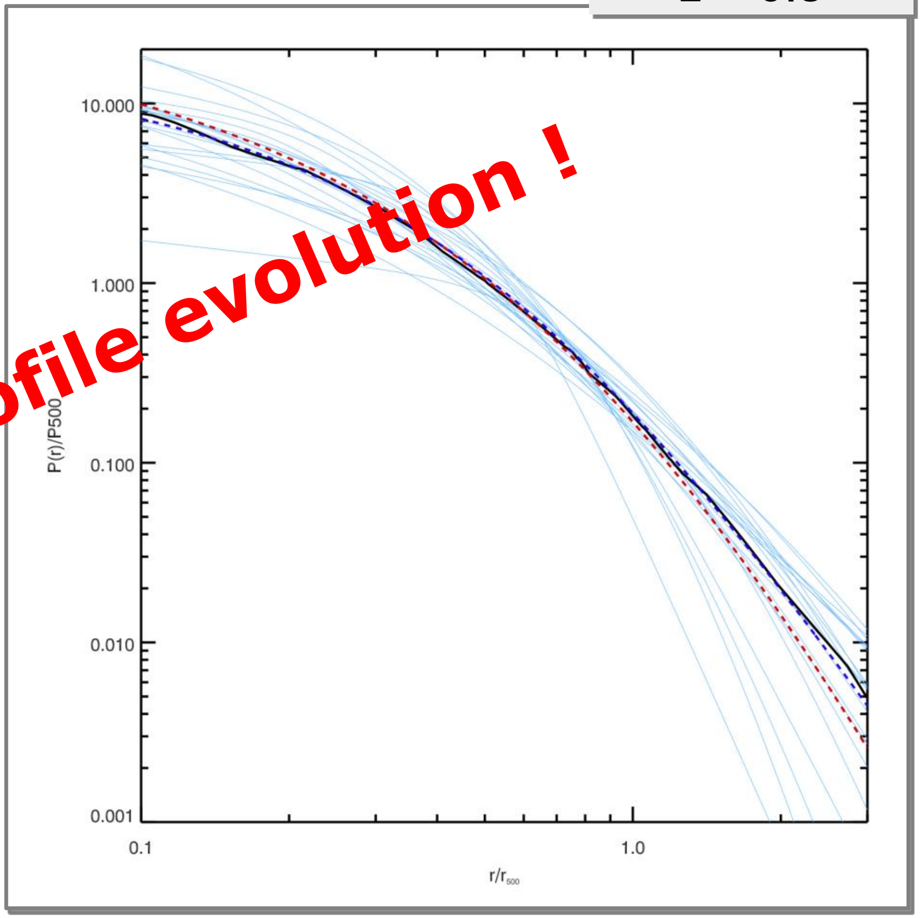


Mass scaled pressure profiles

z < 0.5



z > 0.5



No Pressure profile evolution !

Red: Arnaud Profile
Dot Blue: Planck collaboration. 2013 (Z<0.5)

Black: our analysis
Light Blue: individual profiles

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Conclusions

- Clusters of galaxies are powerful tools for cosmological and astrophysical investigations
- SZ Observations have opened a new and promising window of investigation related to the clusters of galaxies, large scale structure and cosmology.
- Here we focused on reviewing just some of the main scientific results obtained in SZ by Planck
- We also presented a preliminary results on the analysis of the pressure profile of clusters of galaxies observed by Planck at z>0.5 that indicates that there is no evolution compared with local profiles.
- It will be possible to extend to lower Compton SNR (SPT detected clusters?) and/or combination with X-ray stacking
- By-product: temperature measurements independent from X-rays (could help us constrain H0 or calibrate temperatures in nearby cluster catalogs).

THE END

The Planck SZ catalogue

1653 SZ detections
0<Z<1

TABLE 5

NUMBER COUNTS AT 2 σ LEVEL DETECTION FOR THE C/S 400 GHz CHANNEL

Models	$N(>2\bar{F}_\nu^{\rm noise})$ at 400 GHz: With ICM Evolution	$N(>2\bar{F}_\nu^{\rm noise})$ at 400 GHz: Without ICM Evolution
CDM; $\Omega = 1.0$; $h = 0.5$:		
$n = 1$........	1063	3459
$n = 0.8$	1220	3792