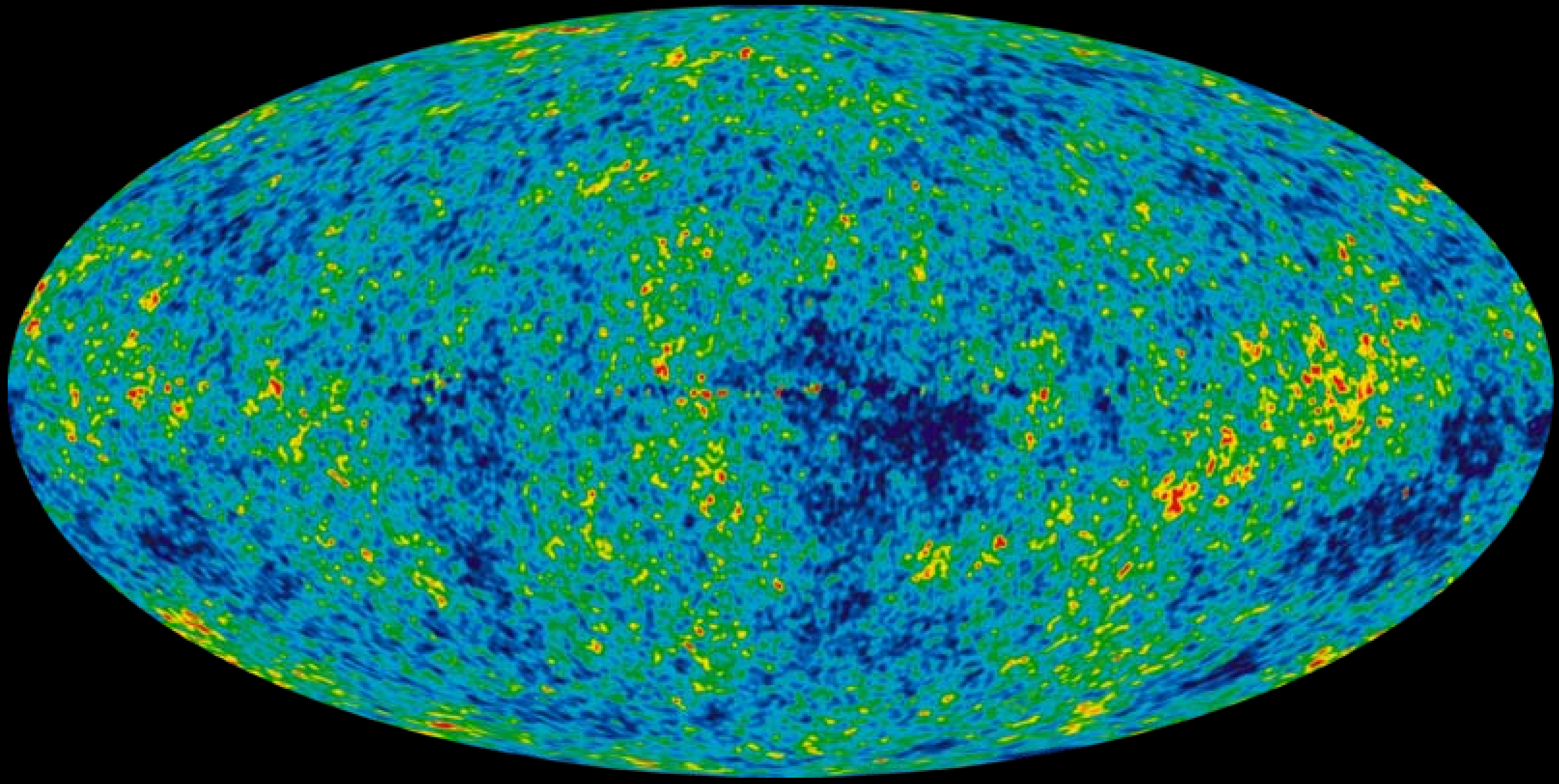
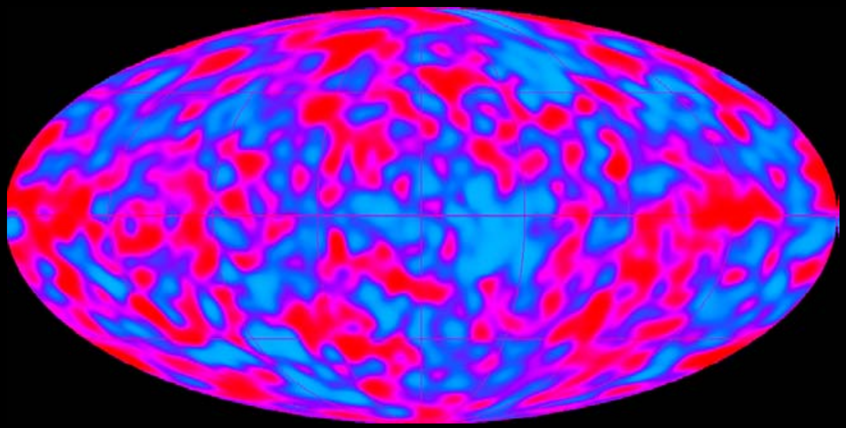


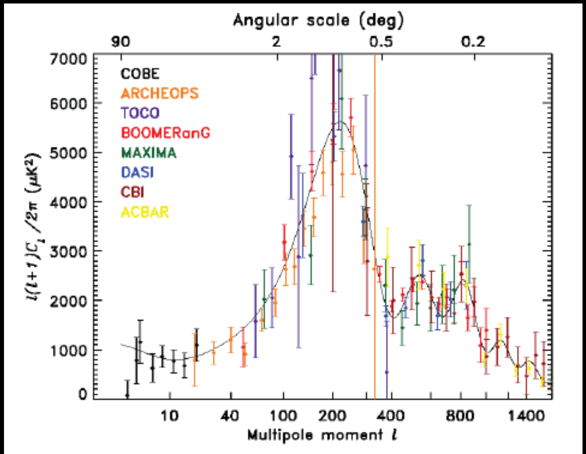
Comparing Planck first results with 7-yr WMAP

Yin-Zhe MA

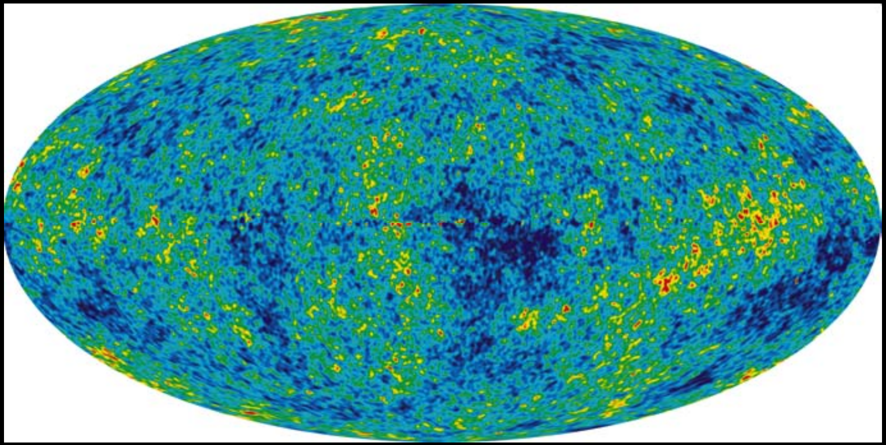
UBC/CITA

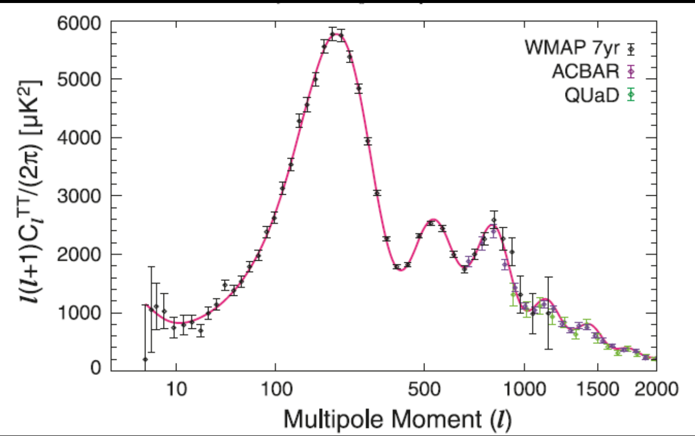
Yin-Zhe Ma, Gary Hinshaw, Douglas Scott, in preparation





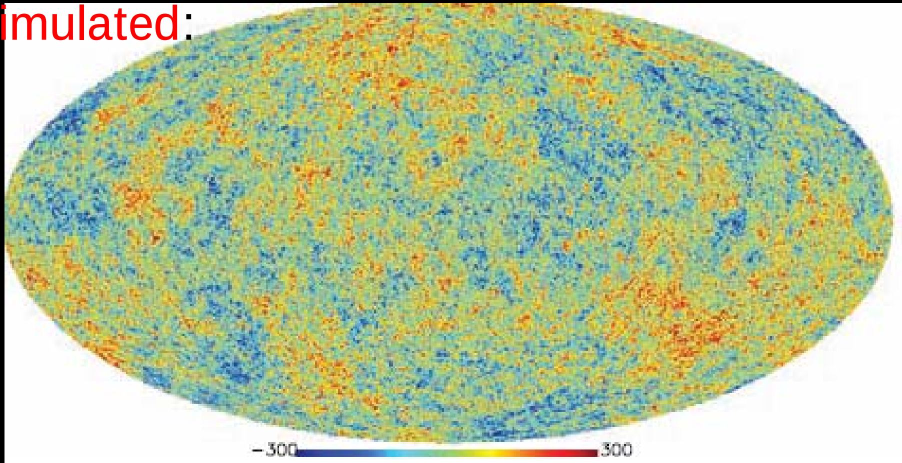
Angular scale (deg)
90
2
0.5
0.2
7000
6000
5000
4000
3000
2000
1000
0
COBE
ARCHEOPS
TOCO
BOOMERanG
MAXIMA
DASI
CBI
ACBAR
$l(l+1)C_l/2\pi$ (μK^2)
10
40
100
200
400
800
1400
Multipole moment l



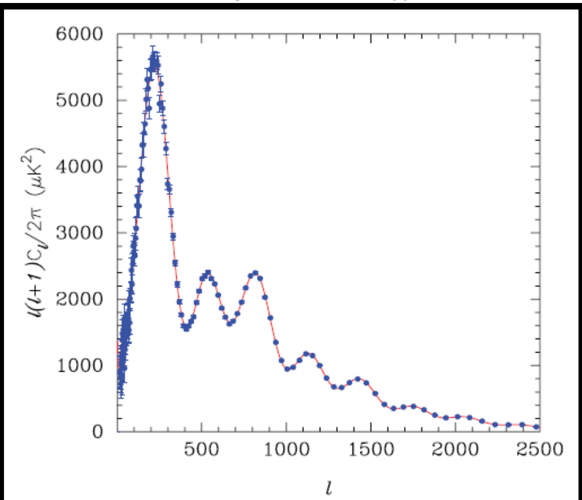


6000
5000
4000
3000
2000
1000
0
WMAP 7yr
ACBAR
QUaD
$l(l+1)C_l^{TT}/(2\pi)$ [μK^2]
10
100
500
1000
1500
2000
Multipole Moment (l)

Simulated:

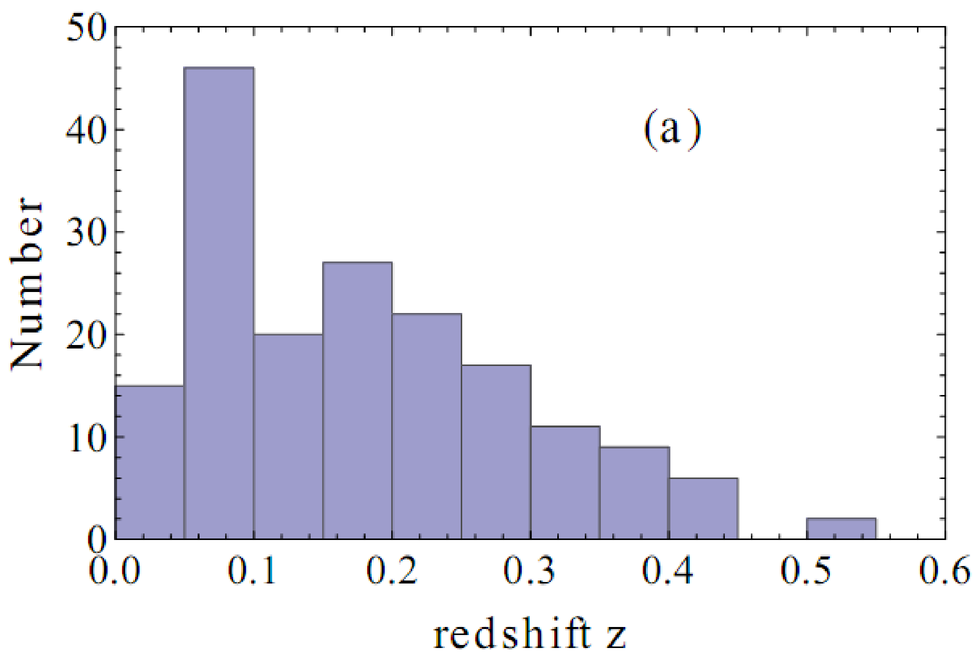


−300
300

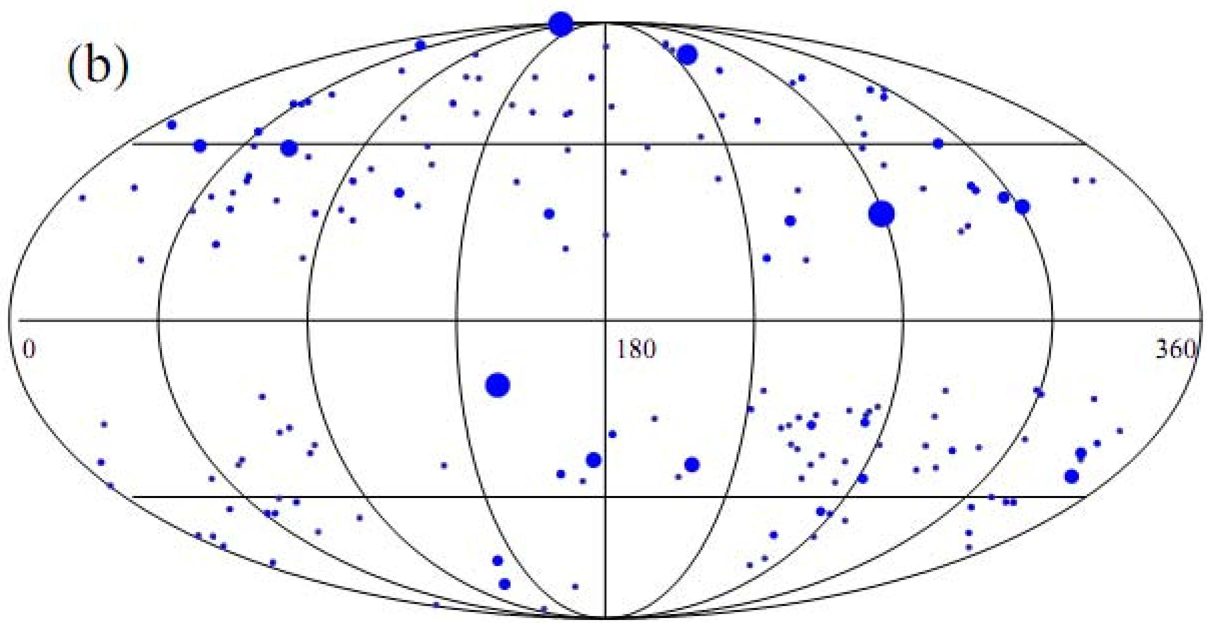


6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi$ (μK^2)
500
1000
1500
2000
2500
l

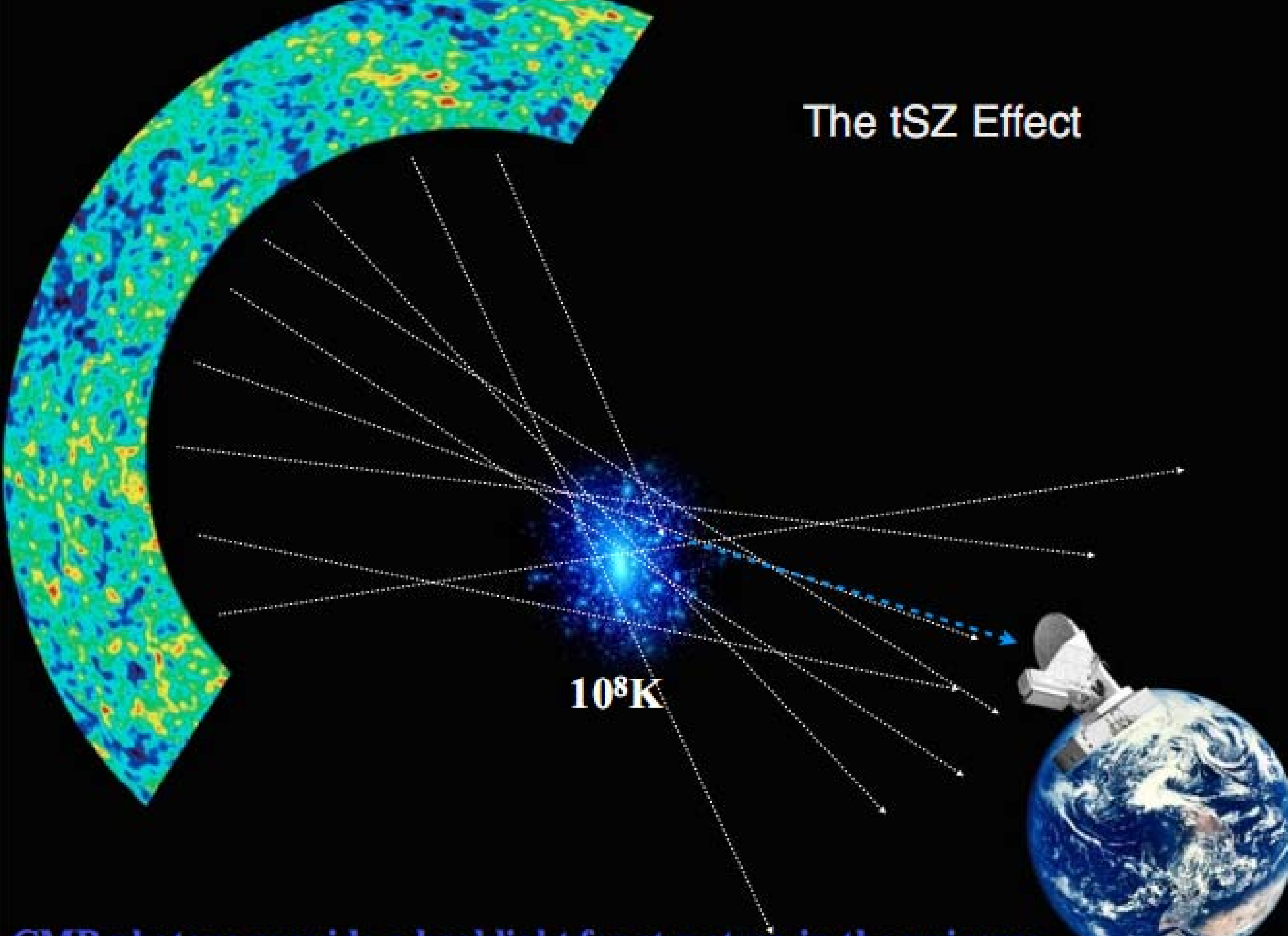
- Anomalies of CMB (alignment…)
- B mode polarization
- Gravitational Lensing of CMB
- Non-gaussianity: beyond the power spectrum
- Kinetic and thermal SZ effect
- …(something completely new)



Distribution of 175 clusters



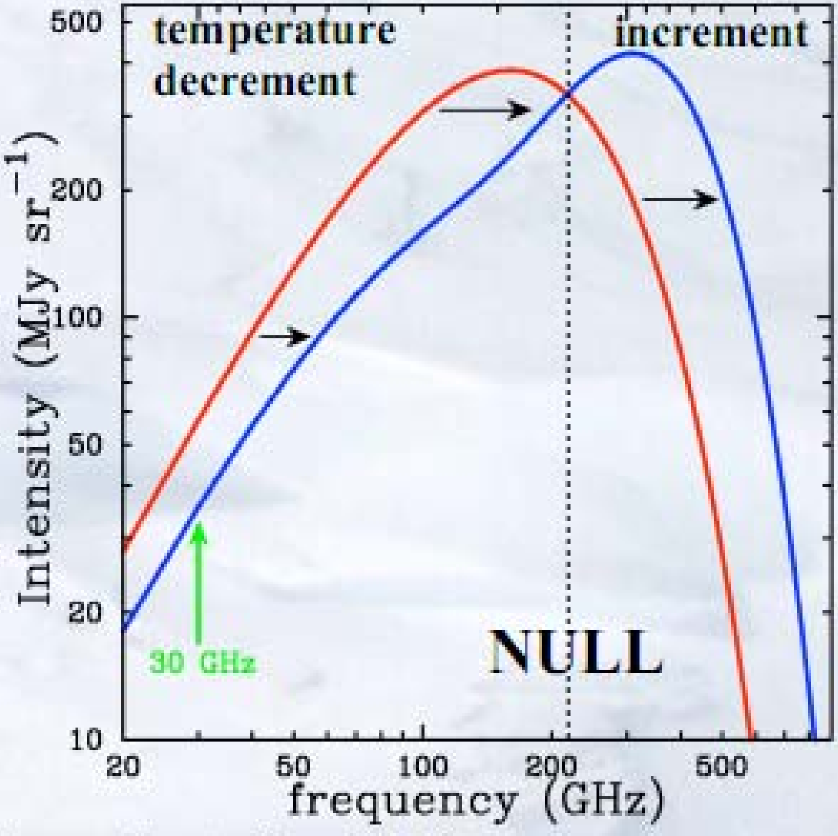
The tSZ Effect



CMB photons provide a backlight for structure in the universe.

thermal Sunyaev-Zel'dovich effect

- **1-2% of CMB photons traversing galaxy clusters are inverse Compton scattered to higher energy**



- **Surface Brightness of the SZ effect independent of redshift**

$$\frac{\Delta T_{cmb}}{T_{cmb}} \equiv f_\nu(x) y = f_\nu \left(\frac{k_B \sigma_T}{m_e c^2}\right) \int n_e(l) T_e(l) dl$$

Thermal SZ effect:

$$\frac{\Delta T}{T} = \left[\eta\frac{e^{\eta}+1}{e^{\eta}-1} - 4\right] y \equiv g_{\nu} y$$

$$g_{\nu} \equiv (\eta(e^{\eta}+1)/(e^{\eta}-1)) - 4$$

$$\eta = \frac{h\nu}{k_B T_{\rm CMB}} = \frac{h\nu_0}{k_B T_0} = 1.76\left(\frac{\nu_0}{100{\rm GHz}}\right)$$

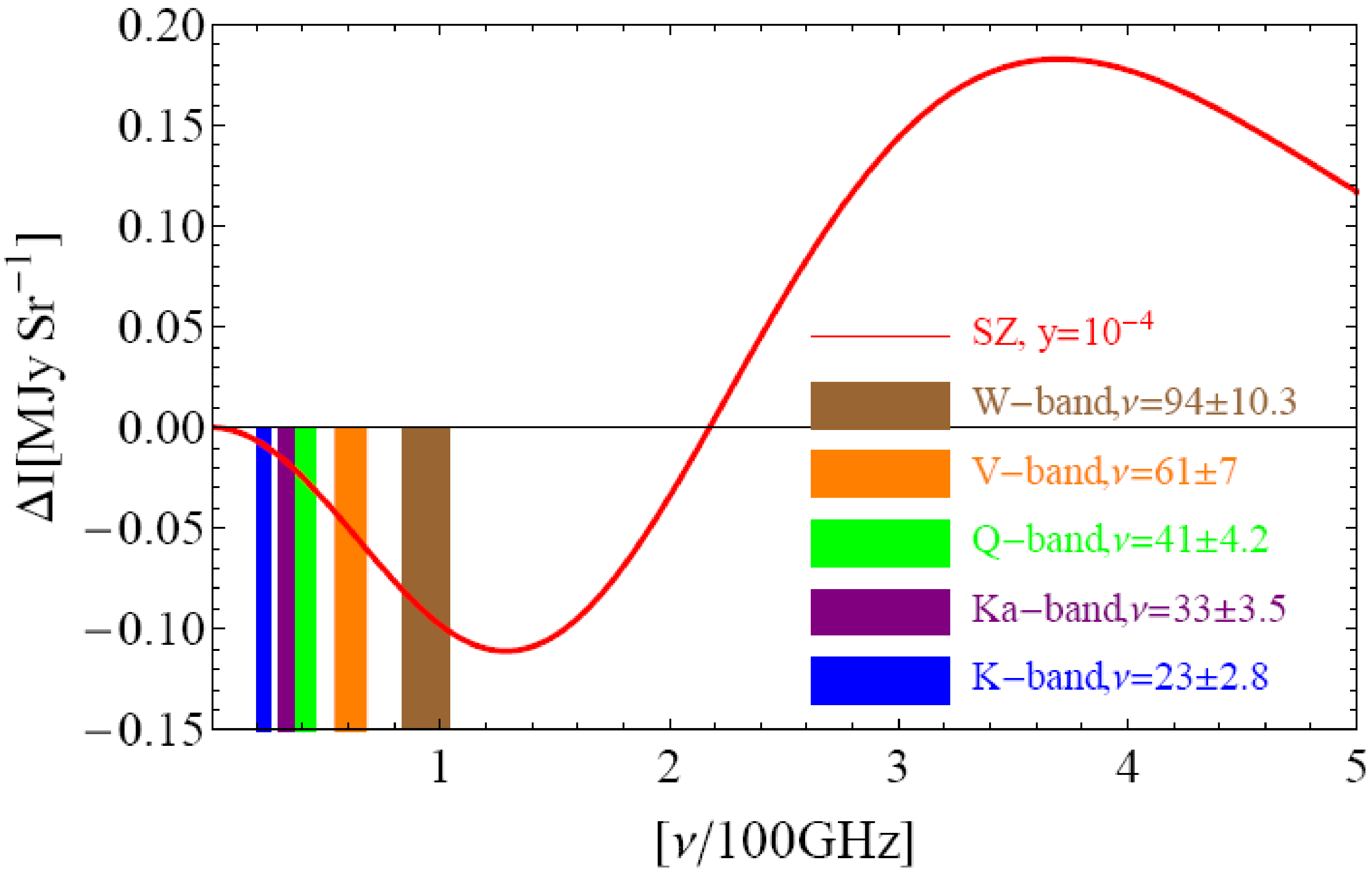
$$y = \frac{k_B \sigma_T}{m_e c^2}\int_0^l T_e(l) n_e(l)\, {\rm d}l$$

- Planck released its Early SZ catalogue 189 sources, in which 175 redshifts are known.
- Planck has also detected the sizes of the clusters, their positions on the sky (l,b), and their Compton Y-parameter.

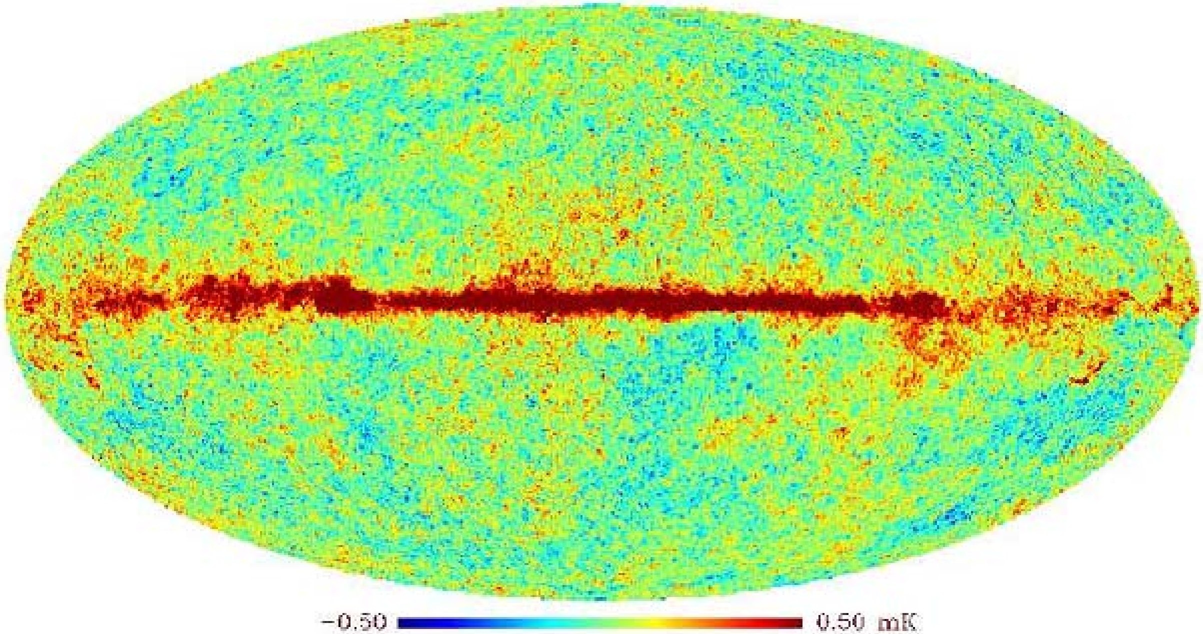
- We would like to find these clusters in WMAP and test the consistency between WMAP and Planck.

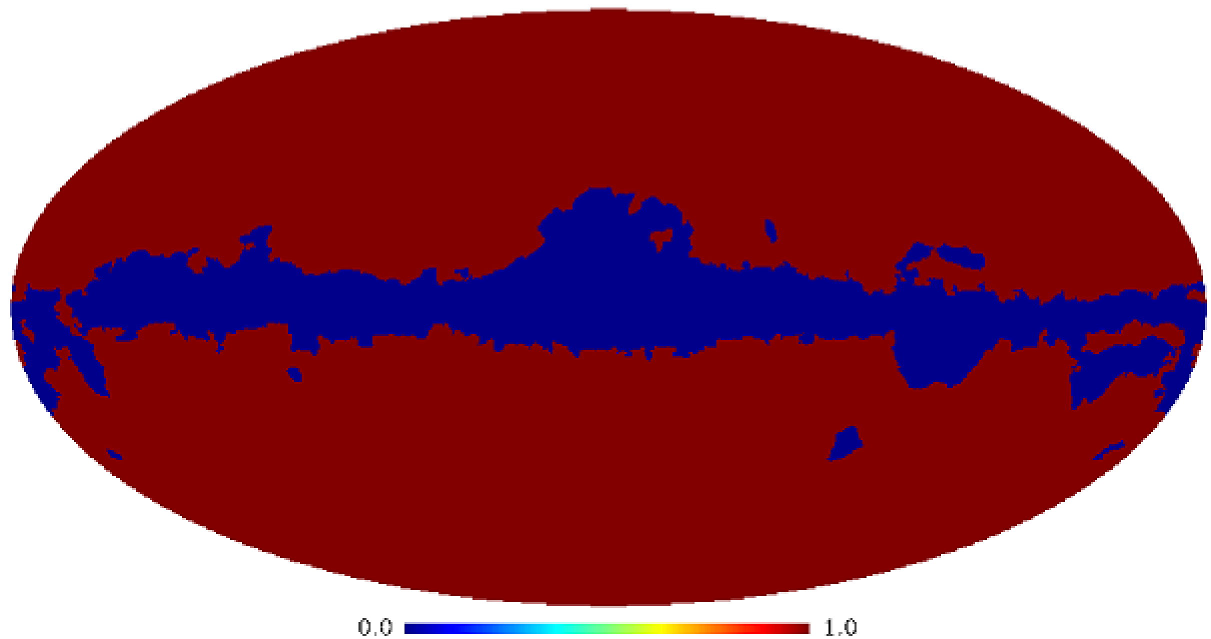
$$Y = \int y \, \mathrm{d}\Omega, \qquad D_A^2 Y = (\sigma_T / m_e c^2) \int P dV$$

Y [arcmin^2]



W-band is the preferable band to use.


−0.50
0.50 mK


0.0
1.0

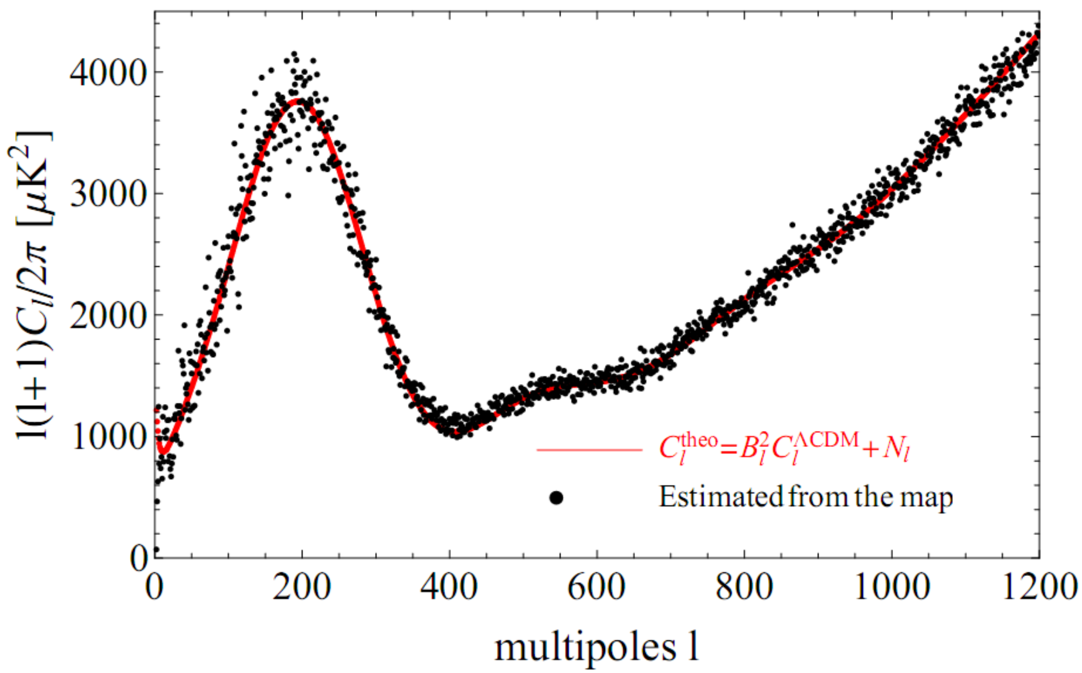
- Now we need to filter the map to search for clusters

Pure CMB and point sources:

$$\Delta T(\hat{r}) = c \sum_i S_i \delta(\hat{r}, \hat{r}_i) + \sum_{lm} a_{lm} Y_{lm}(\hat{r})$$

$$c = c_* \frac{\left(2\sinh(\frac{\eta}{2})\right)^2}{\eta^4}, \; c_* = \frac{1}{2k_B}\left(\frac{hc}{kT_{CMB}}\right)^2 \simeq \frac{10\mathrm{mK}}{\mathrm{MJy/sr}}$$

$$a_{lm}^{\mathrm{tot}} = B_l a_{lm}^{CMB} + n_{lm}$$



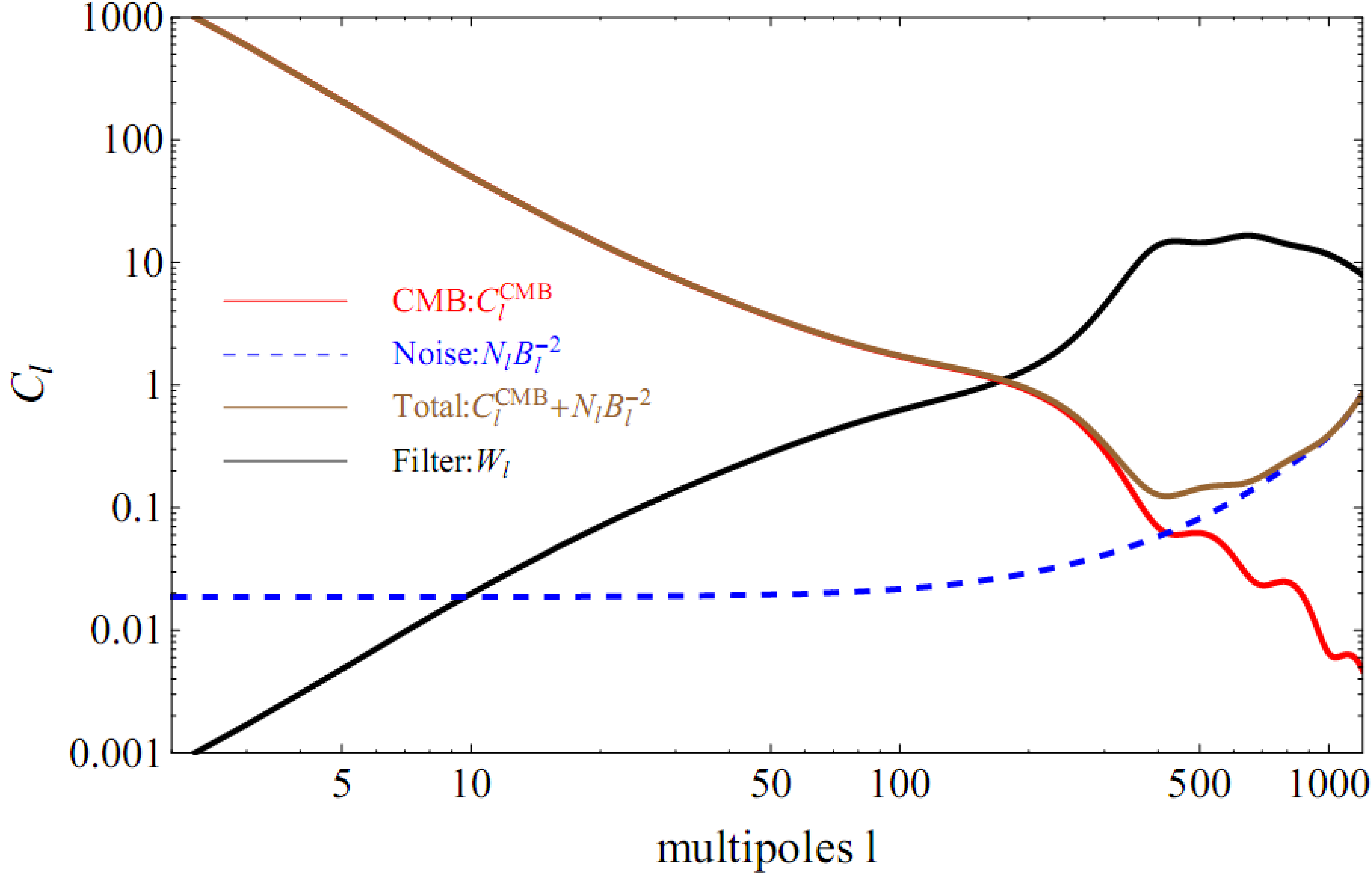
$$\Delta T^{\mathrm{obs}}(\hat{r}) = c\sum_i S_i \left[\sum_l \left(\frac{2l+1}{4\pi} P_l(\cos(\hat{r}_i,\hat{r}))\right) B_l\right] + \sum_{lm} a_{lm}^{\mathrm{tot}} Y_{lm}(\hat{r}),$$

$$\Delta \tilde{T}(\hat{r}) = c\sum_i S_i \left[\sum_l \left(\frac{2l+1}{4\pi} P_l(\cos(\hat{r}_i,\hat{r}))\right) B_l W_l\right] + \sum_{lm} a_{lm}^{\mathrm{tot}} W_l Y_{lm}(\hat{r}).$$

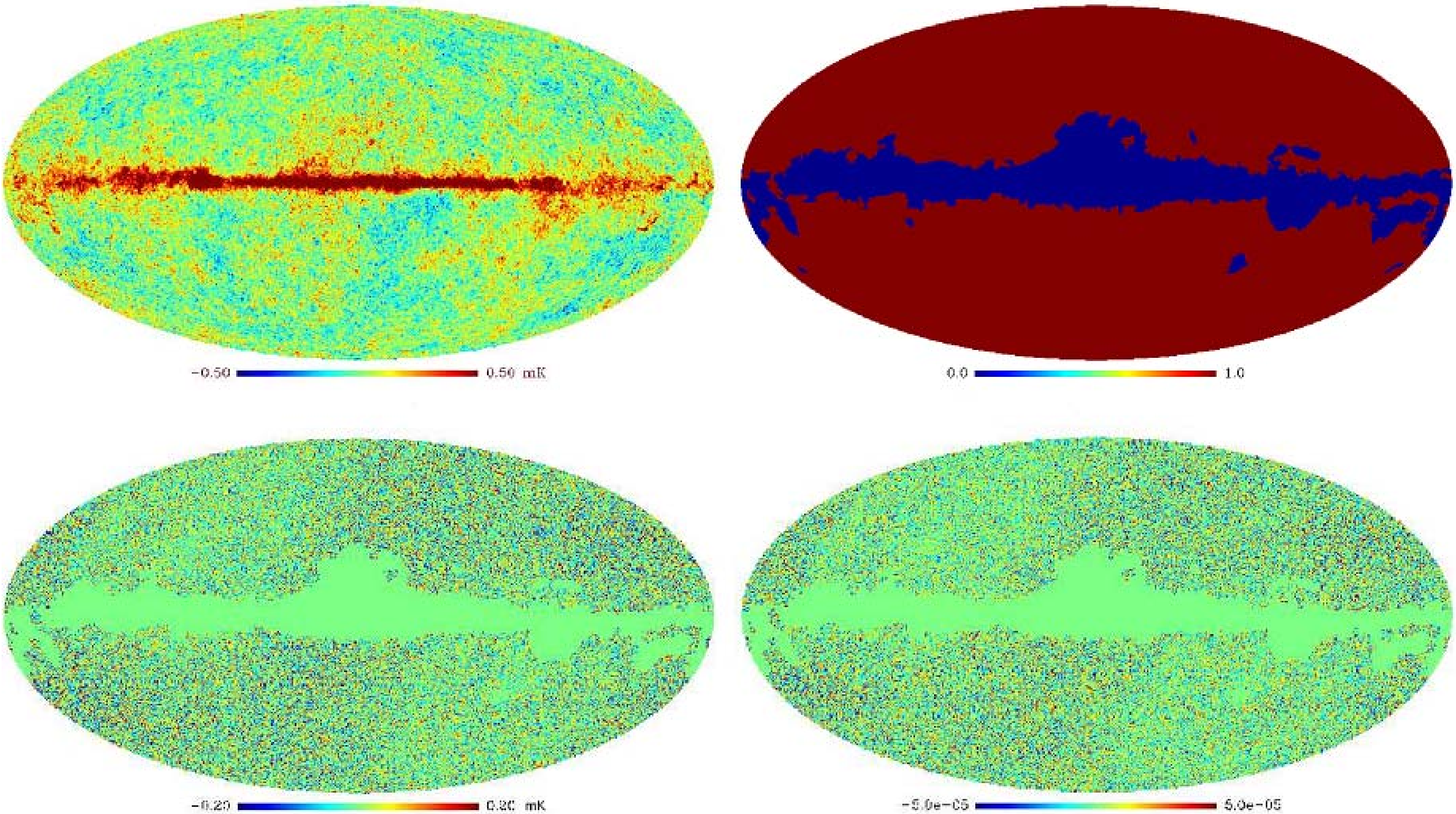
If no CMB/noise contamination: $A = c\sum_l \left(\frac{2l+1}{4\pi}\right) W_l B_l$

Minimizing: $\sigma^2 = Var\left[\frac{\Delta \tilde{T}(\hat{r})}{A}\right] = \frac{\sum_l \left(\frac{2l+1}{4\pi}\right) C_l^{\mathrm{tot}} W_l^2}{c^2\left[\sum_l \left(\frac{2l+1}{4\pi} B_l W_l\right)\right]^2}$

$$\longrightarrow \qquad W_l \sim \frac{B_l}{B_l^2 C_l^{\mathrm{M}} + N_l} = \frac{B_l}{C_l^{\mathrm{tot}}}.$$



1000
100
10
1
0.1
0.01
0.001
C_l
CMB: $C_l^{\rm CMB}$
Noise: $N_l B_l^{-2}$
Total: $C_l^{\rm CMB} + N_l B_l^{-2}$
Filter: W_l
5
10
50
100
500
1000
multipoles l



Delta_T map

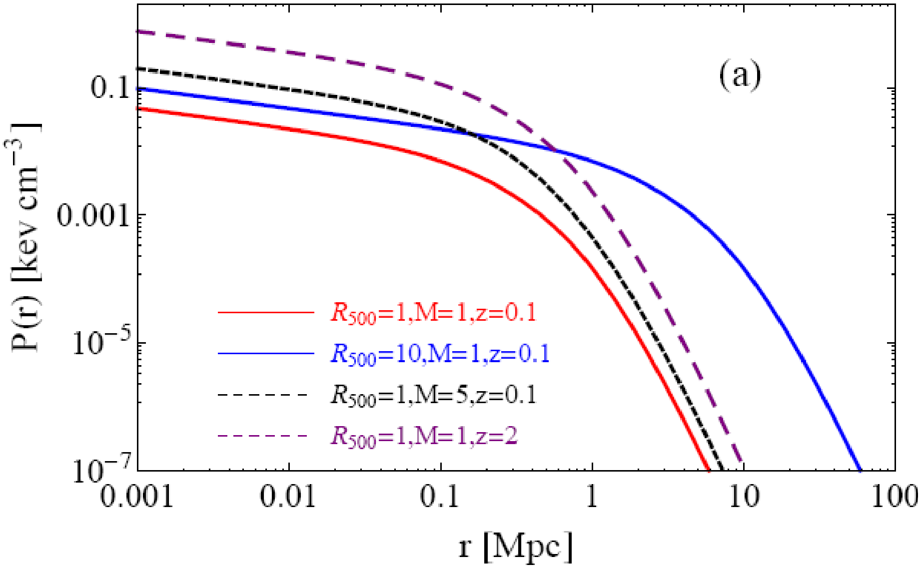
y-map

What is the profile of the cluster before and after filtering?

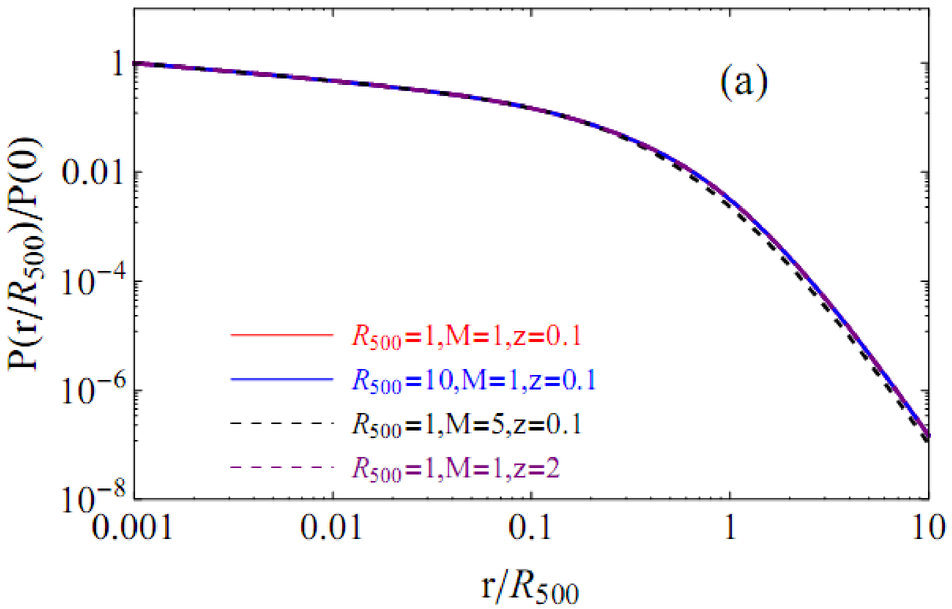
$Y = \int y \, d\Omega,$ $D_A^2 Y = (\sigma_T / m_e c^2) \int P dV$ Y [arcmin^2]

Universal pressure profile

$$\tilde{p}(x) = \frac{P_0}{(c_{500}x)^{\gamma}\left[1+(c_{500}x)^{\alpha}\right]^{(\beta-\gamma)/\alpha}}$$ Arnaud et al. (2010)



The unit of M(mass), R_{500} and θ_{500} are $3\times10^{14}M_{\odot}$, Mpc and arcmin respectively.



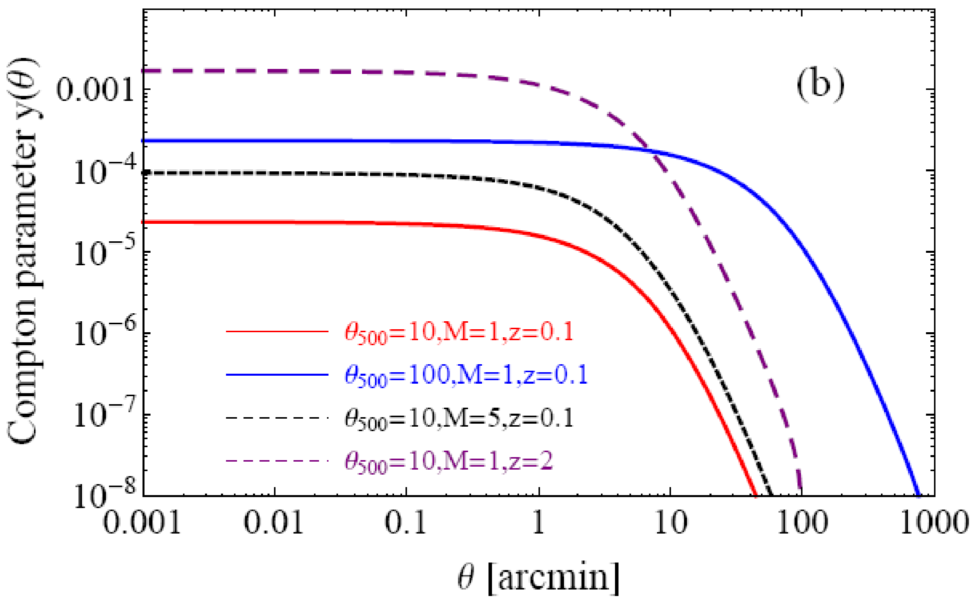
Universal temperature profile

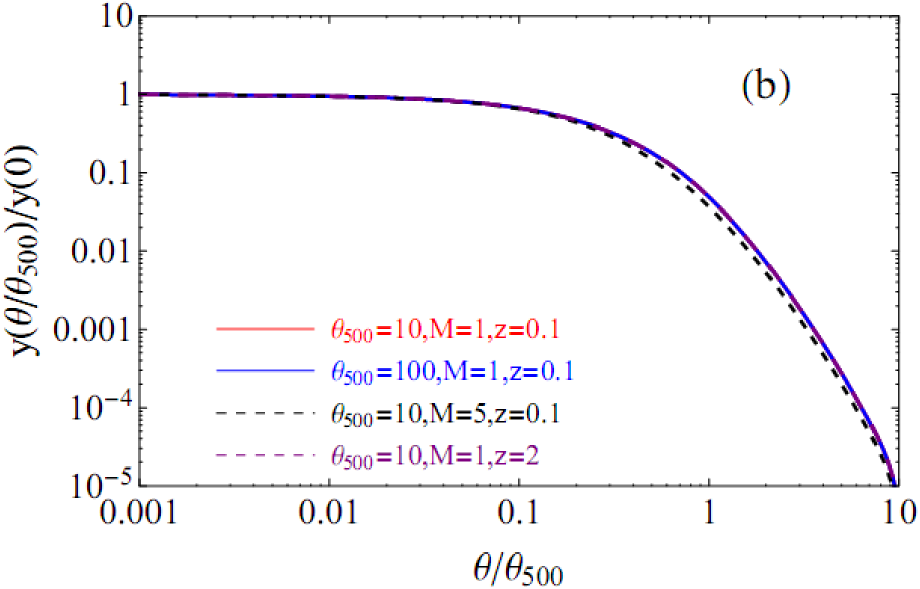
Projection:

$$P_e^{2d}(\theta) = \int_{-\sqrt{r_{\rm out}^2-\theta^2 D_A^2}}^{\sqrt{r_{\rm out}^2-\theta^2 D_A^2}} dl P\left(\sqrt{l^2+\theta^2 D_A^2}\right) \ [\mathrm{keV cm^{-3}}]$$

$$\Delta T_{SZ}(\theta) = g_\nu T_{CMB} P_e^{2d}(\theta) \frac{\sigma_T}{m_e c^2}$$

$$y(\theta) = \left(\frac{1}{g_\nu}\right) \frac{\Delta T_{SZ}(\theta)}{T_{CMB}}$$





What is the shape of the profile after filtering?

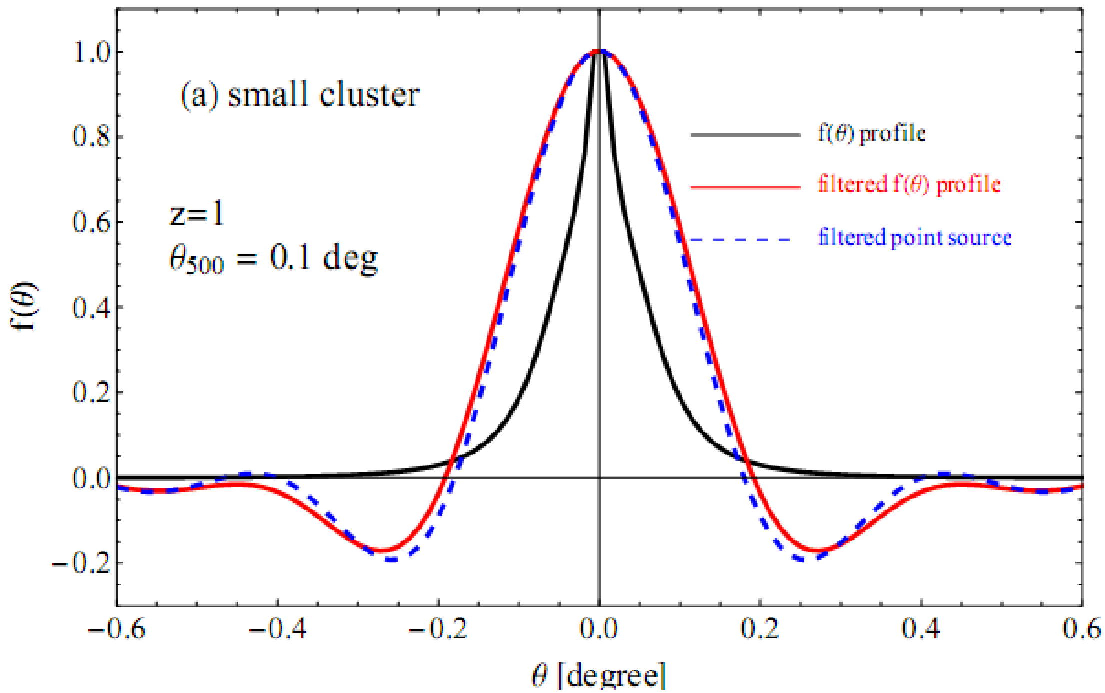
Full-sky cluster-only map: $$x(\hat{r}) = \sum_i f(\Theta(\hat{r}_i, \hat{r}))$$

$$x(\hat{r}) = \sum_i f(\Theta(\hat{r}_i, \hat{r})) = \sum_{lm} a_{lm} Y_{lm}(\hat{r})$$

$$a_{lm} = \int x(\hat{r}) Y^*_{lm}(\hat{r}) d\hat{r}$$
$$= \sum_i \left[\int f(\Theta(\hat{r}_i, \hat{r})) Y^*_{lm}(\hat{r}) d\hat{r} \right]$$

$$\tilde{x}(\hat{r}) = (W * x)(\hat{r}) = \sum_i \left[\int d\hat{r}' f(\Theta(\hat{r}_i, \hat{r}')) W(\cos(\Theta')) \right]$$

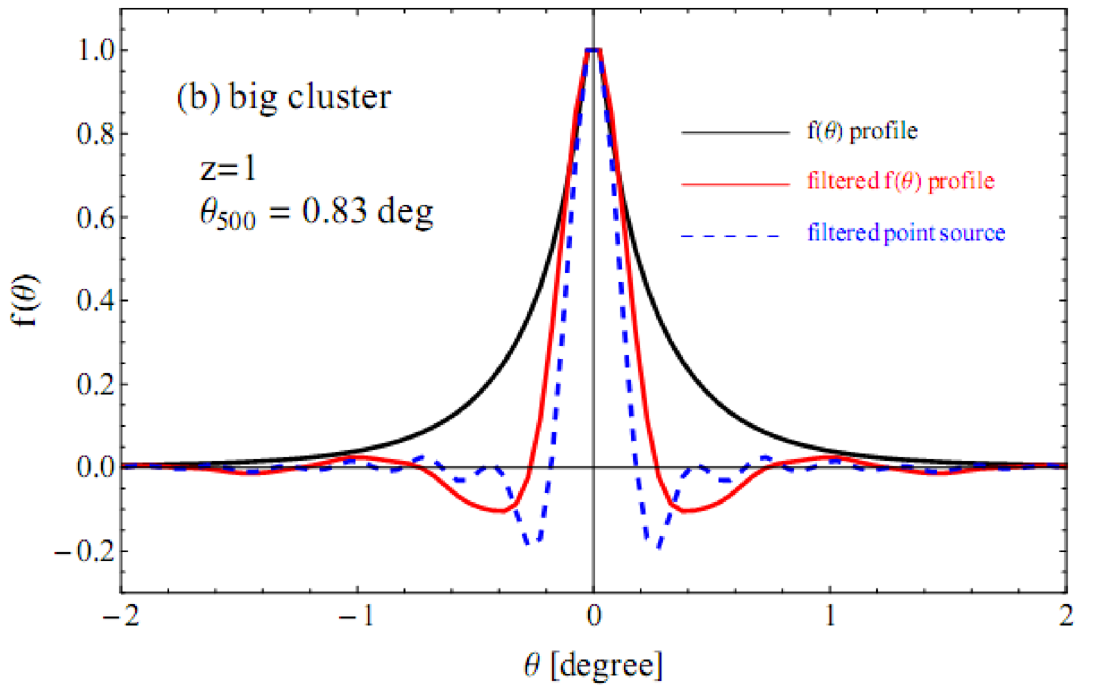
$$W(\cos(\Theta')) = \sum_l \left(\frac{2l+1}{4\pi} W_l P_l(\cos\Theta') \right)$$

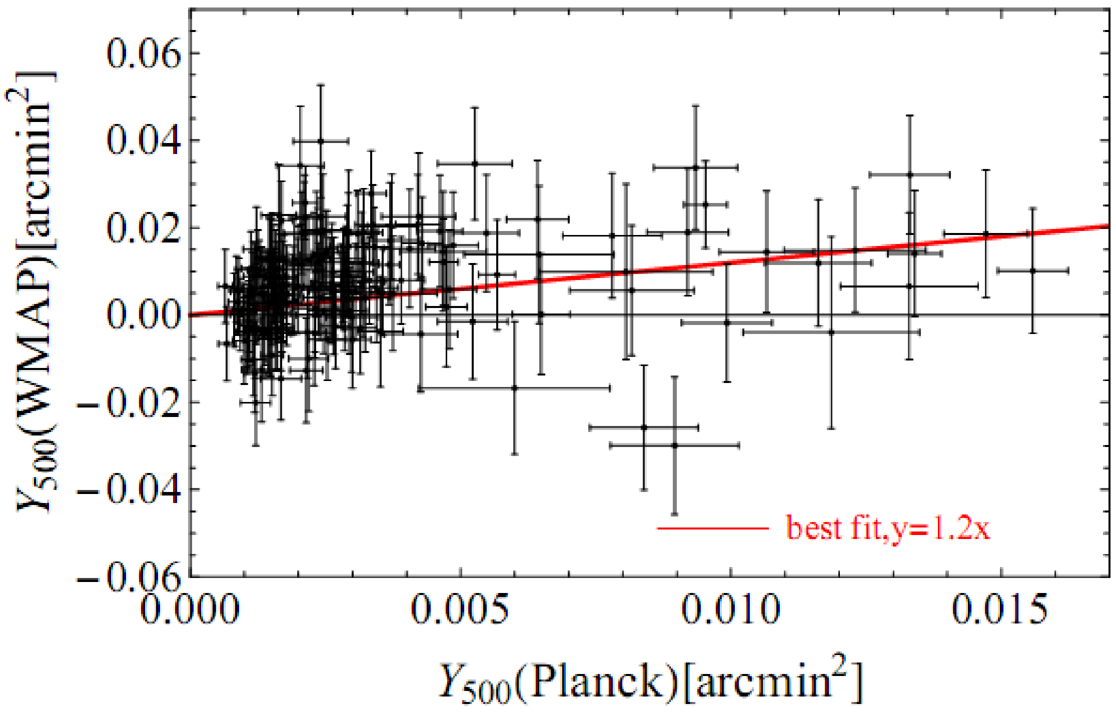


theta_500: the outskirt radius of the cluster where density is 500 of the critial density

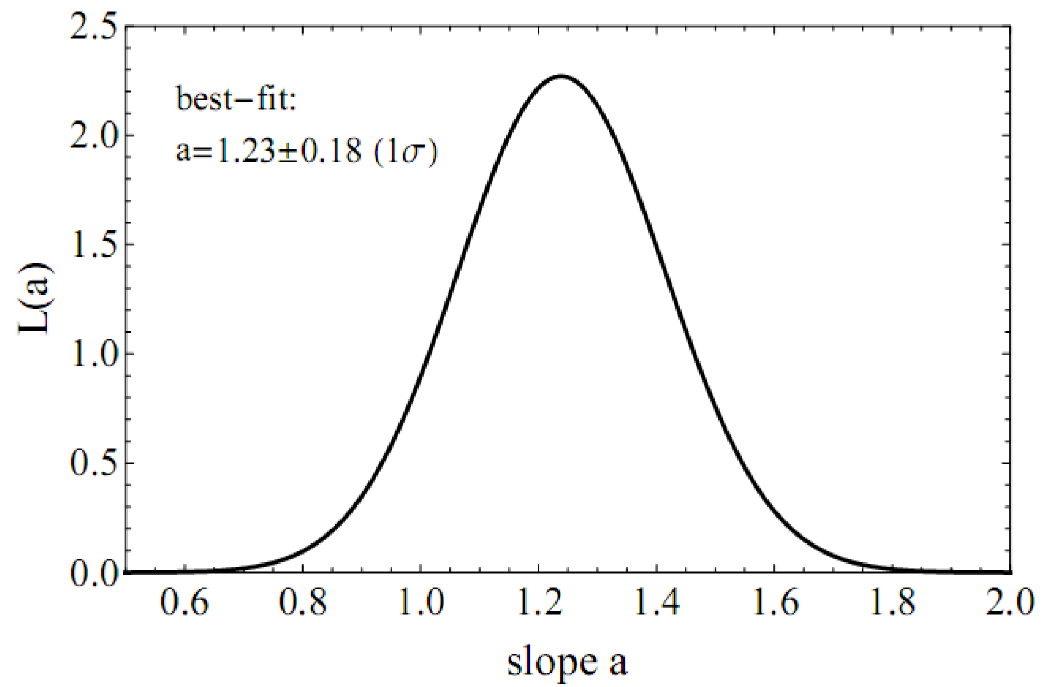
$$Y = \int y \, \mathrm{d}\Omega,$$

Integrates over theta_500.



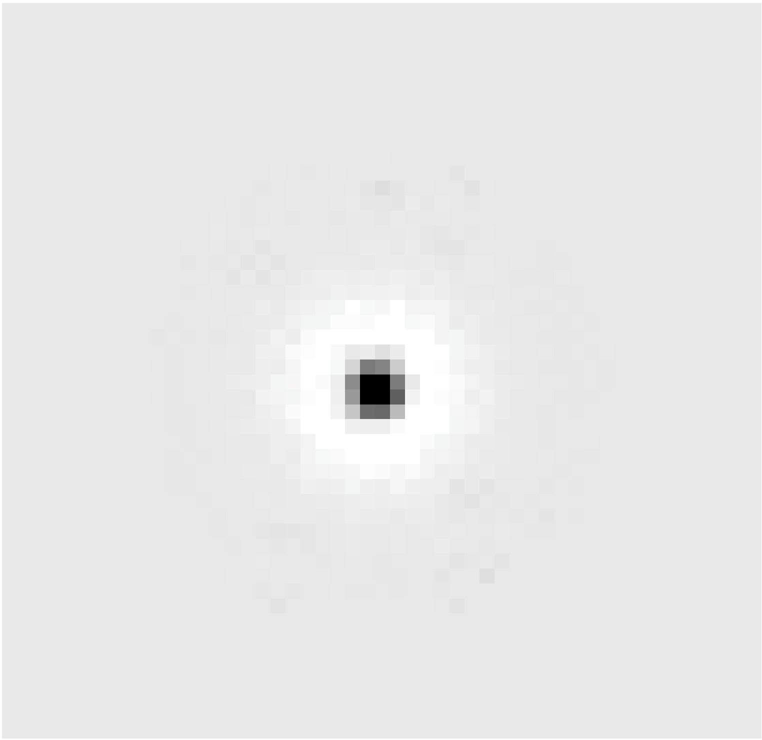


0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
Y_{500}(WMAP)[arcmin^2]
best fit,y=1.2x
0.000
0.005
0.010
0.015
Y_{500}(Planck)[arcmin^2]

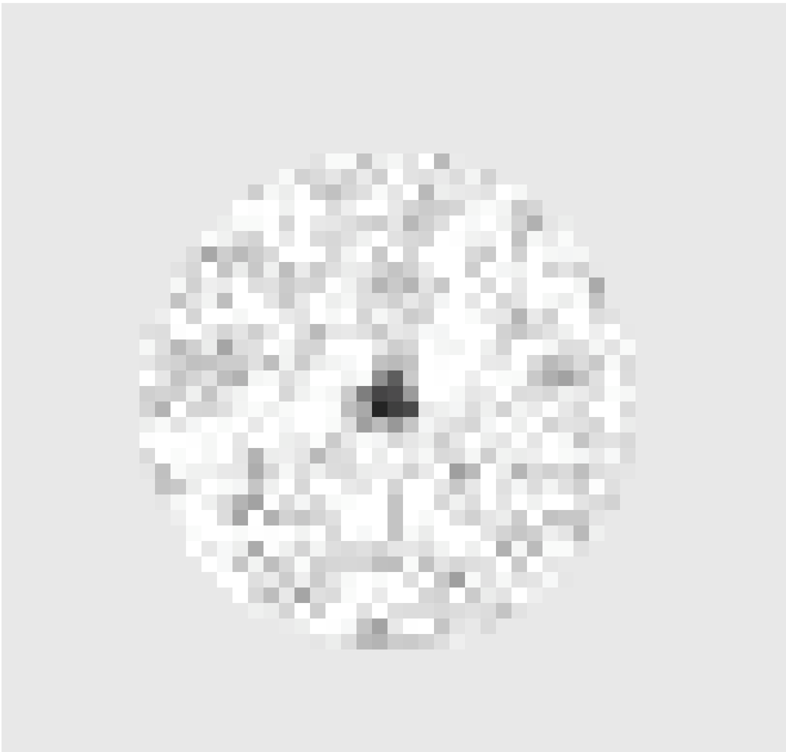


2.5
2.0
1.5
1.0
0.5
0.0
L(a)
best−fit:
a=1.23±0.18 (1σ)
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
slope a

S/N ratio for stacking	WMAP	Planck
$\left(\sum_i Y_i\right) / \left[\sum_i \delta Y_i^2\right]^{1/2}$	8.9	85.2
$\left[\sum_i \left(Y_i/\delta Y_i\right)^2\right]^{1/2}$	16.3	123.3



Stacking pure clusters together



Stacking filtered clusters together from wmap

Summary:

- Planck ESZ catalogue is a useful tool to study the detail profile of galaxy clusters
- We can match-filter the WMAP map to suppress the CMB and noise contribution and therefore obtain a map of clusters.
- Although WMAP gives individual cluster very weak (~0.7 sigma) detection, overall it can give a stack significance at 9 sigma CL.
- In addition, by comparing the Y_planck with Y_WMAP, we find excellent agreement between the two.
- In the near future, we will work on Planck data to fit both tSZ and kSZ component and place constraints on the large scale bulk motion.