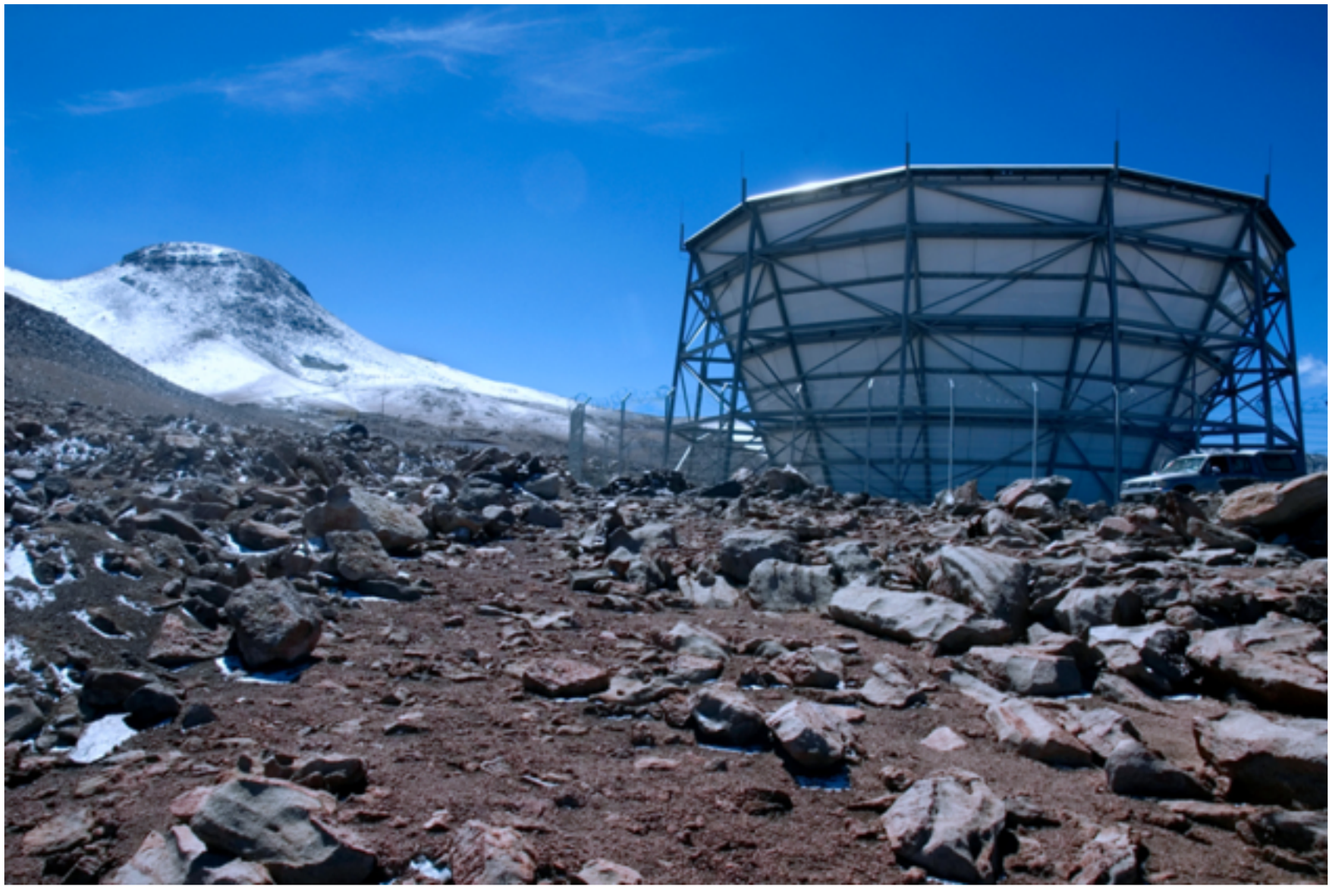
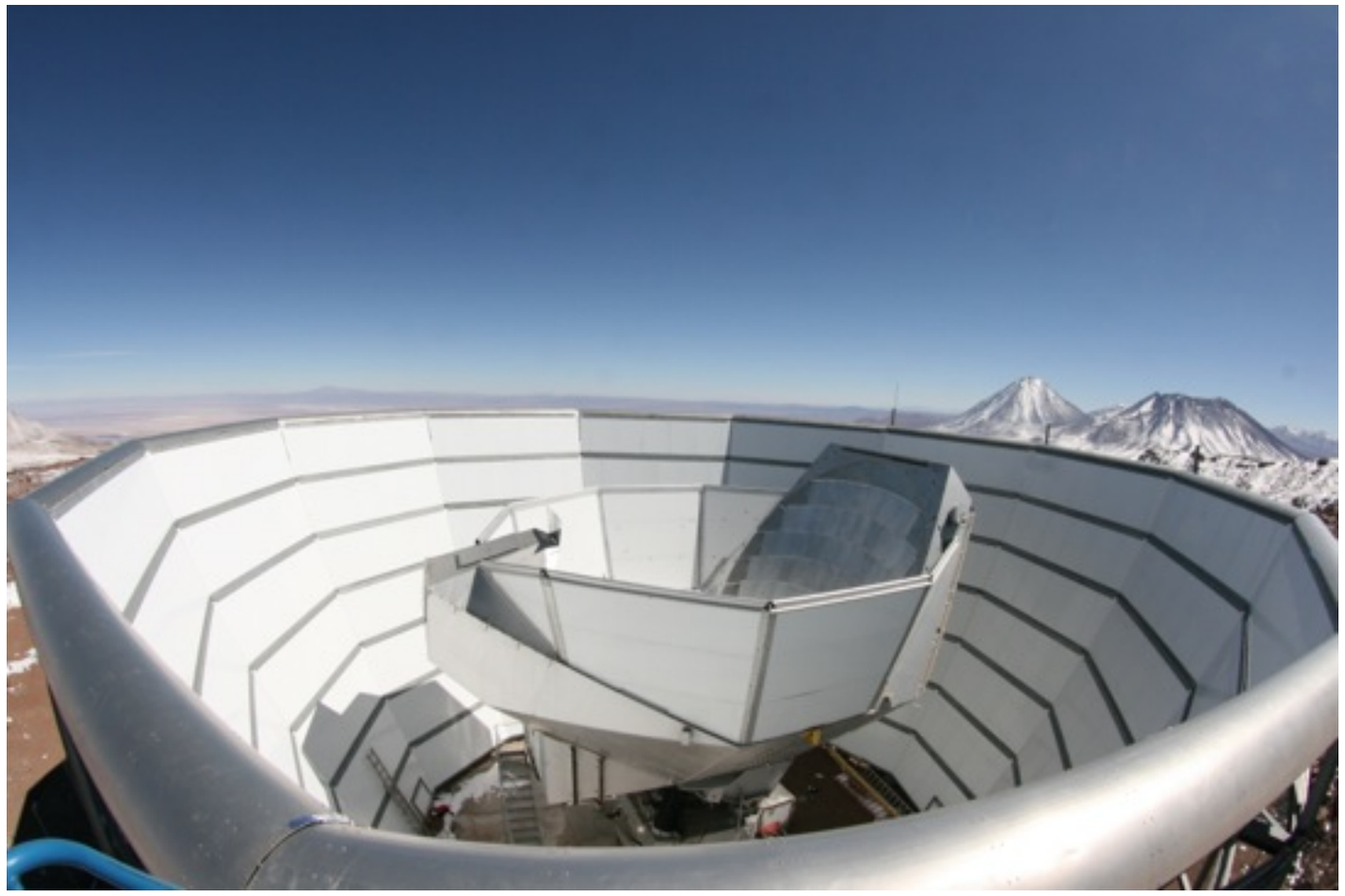
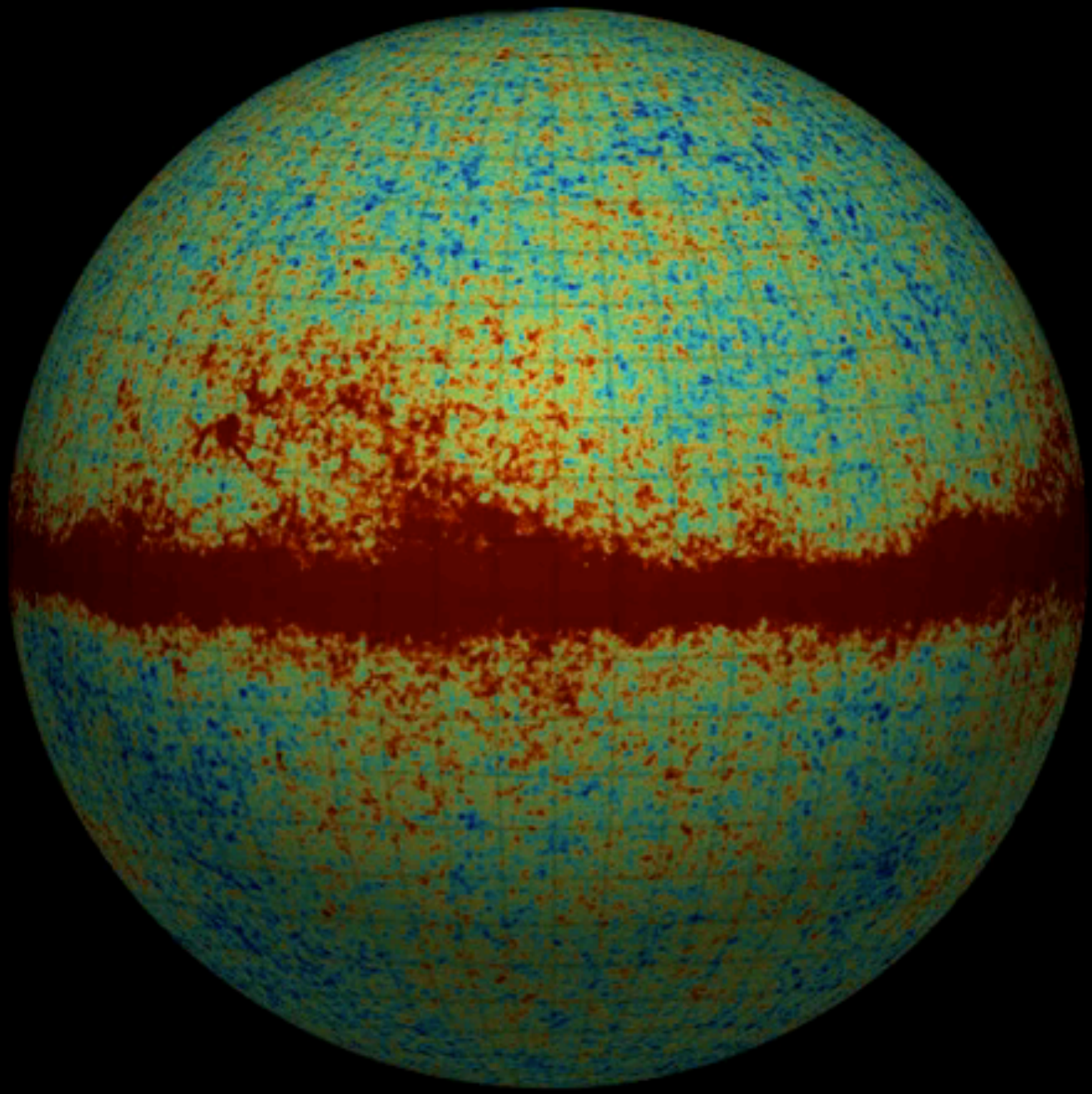
ACTPol results and prospects for CMB S4

Thibaut Louis

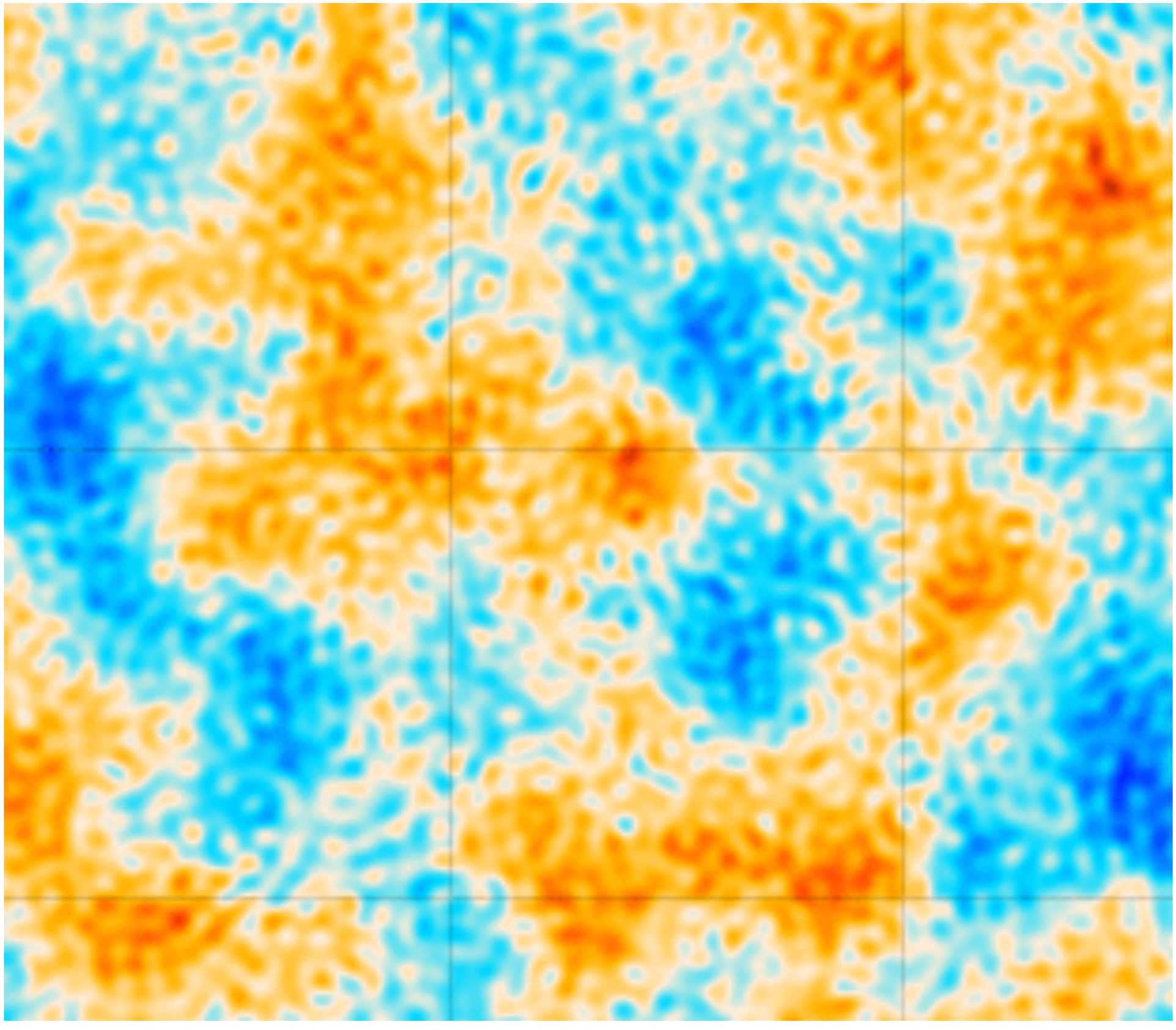




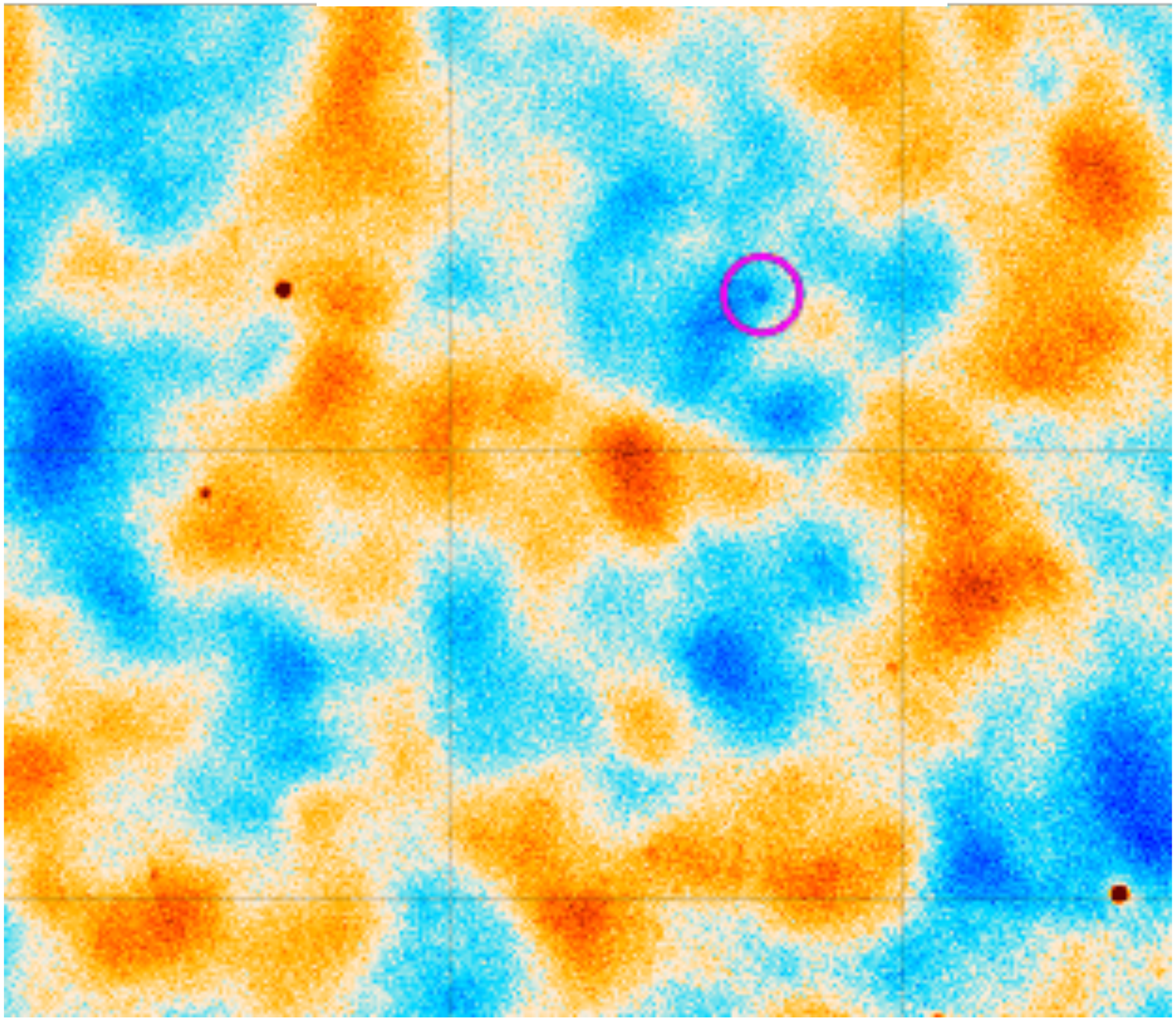
5200 meter elevation, one of the driest places on planet.
6 meter dish : **arcminute resolution**.
Two years of observation (and only 12% of the full data set)



Planck

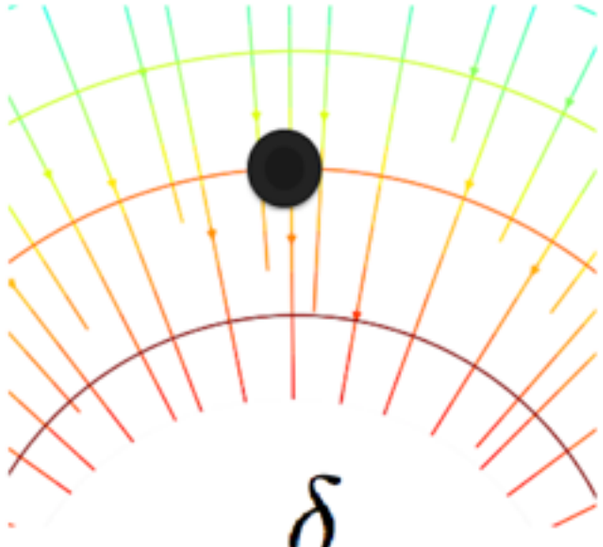


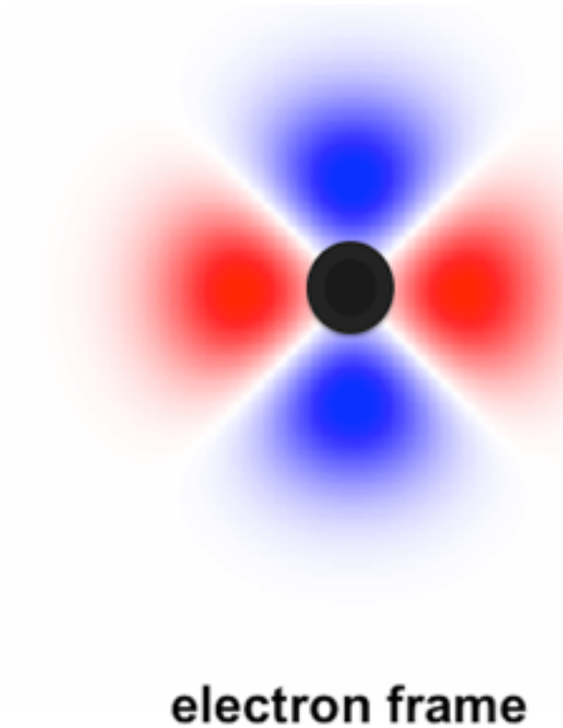
ACTPol



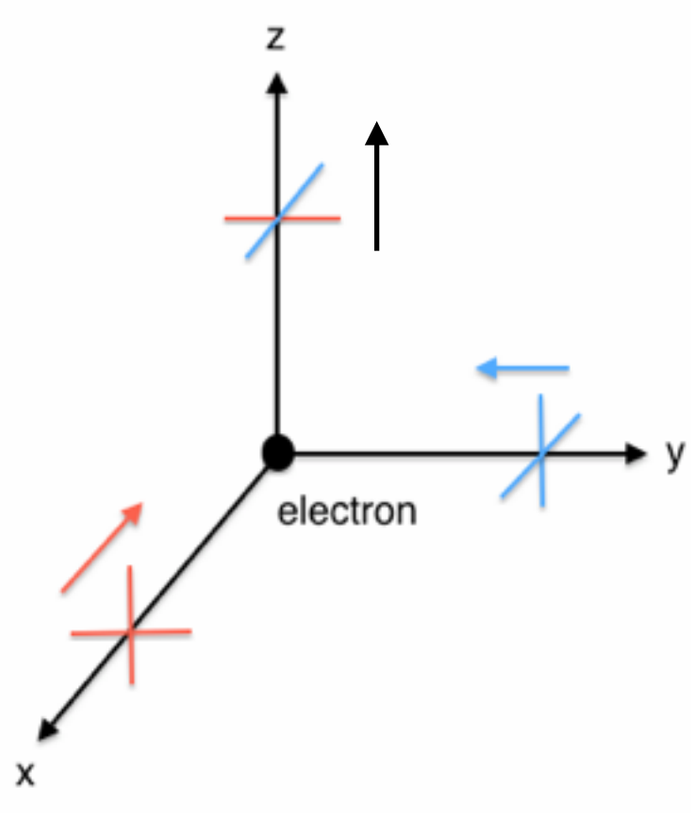
Polarization

An electron falling towards an over density will see a quadrupole anisotropy





Quadrupole scattering an electron results in linear polarization



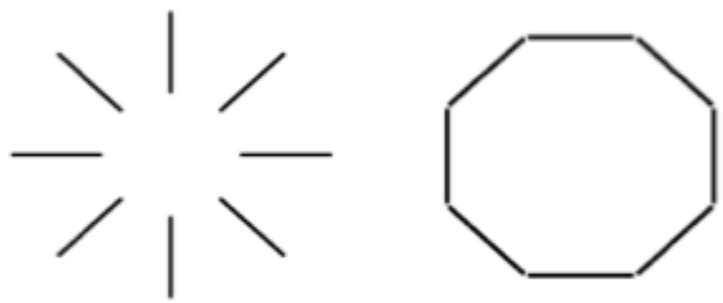
Polarization

Small effect: $\frac{P}{T_{CMB}} \approx 10^{-6}$

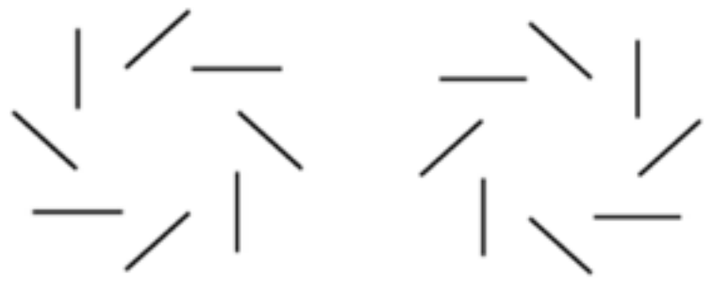
Flows on the last scattering surface only produce E modes polarization

What about B modes?

E modes



B modes



Polarization

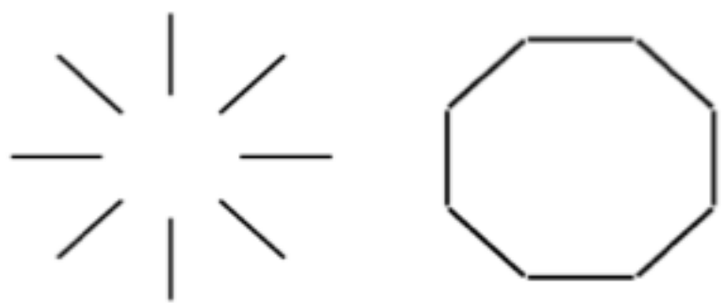
Small effect: $\frac{P}{T_{CMB}} \approx 10^{-6}$

Flows on the last scattering surface only produce E modes polarization

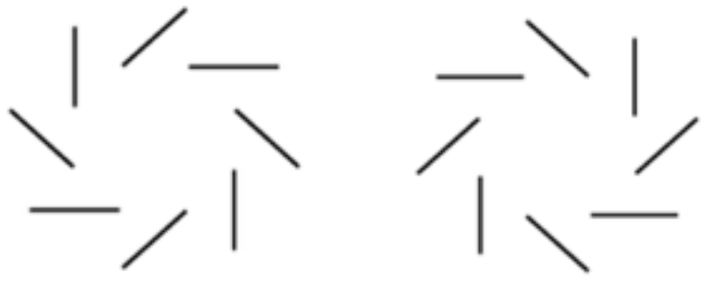
Two sources:

-Primordial gravitational waves

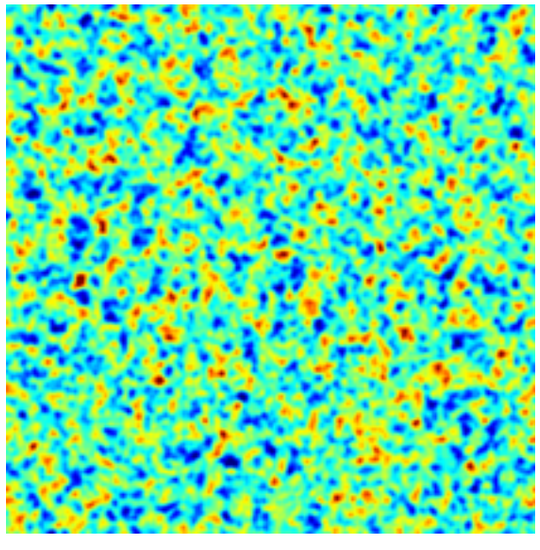
E modes



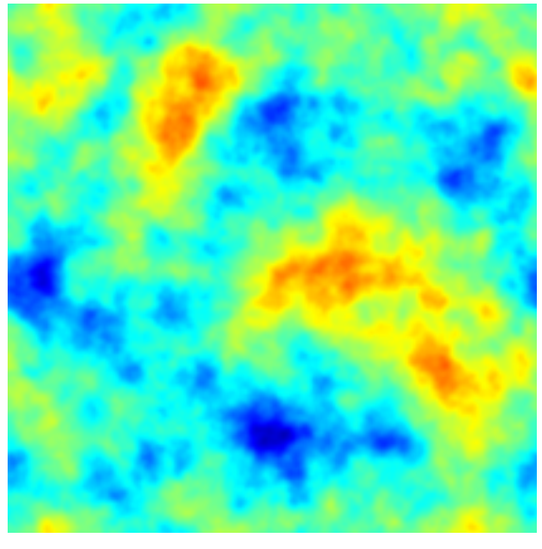
B modes



E ($\pm 20\mu$K)



B ($\pm 0.5\mu$K)



Polarization

Small effect: $\frac{P}{T_{CMB}} \approx 10^{-6}$

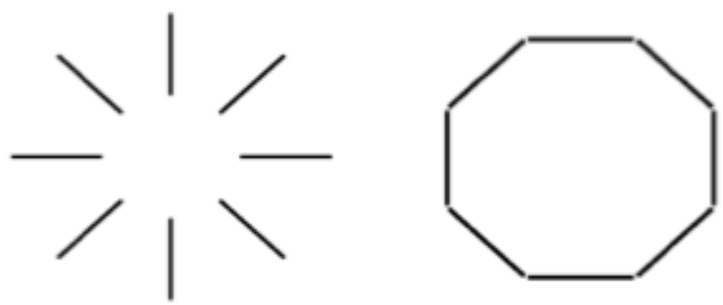
Flows on the last scattering surface only produce E modes polarization

Two sources:

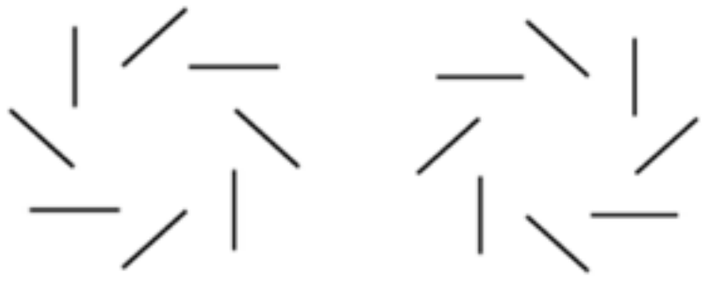
-Primordial gravitational waves

-Lensing of E modes

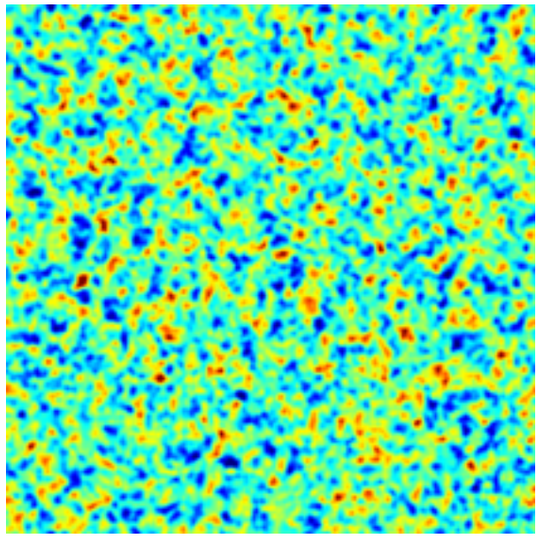
E modes



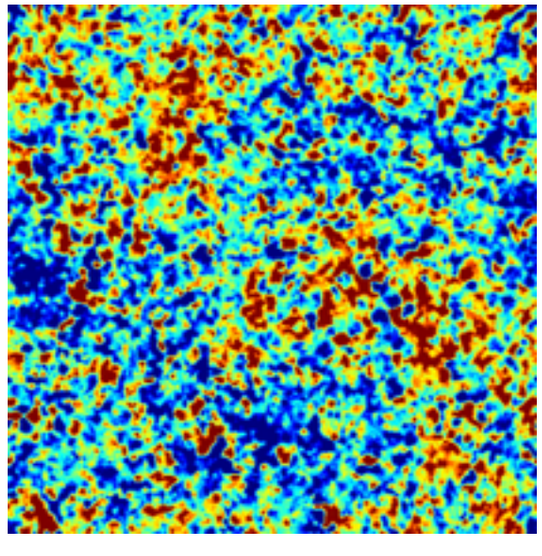
B modes



E ($\pm 20\mu$K)

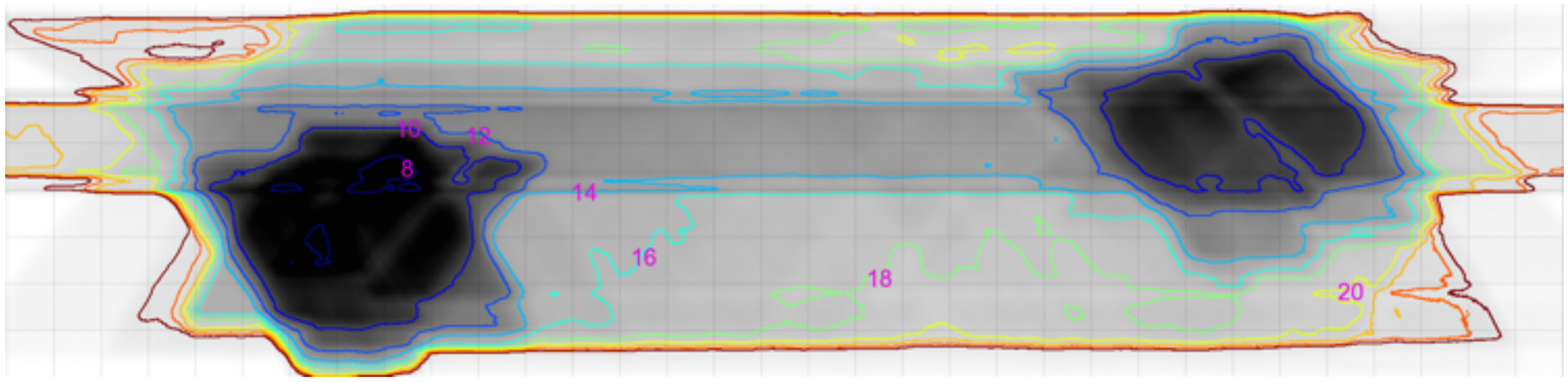


B ($\pm 0.5\mu$K)

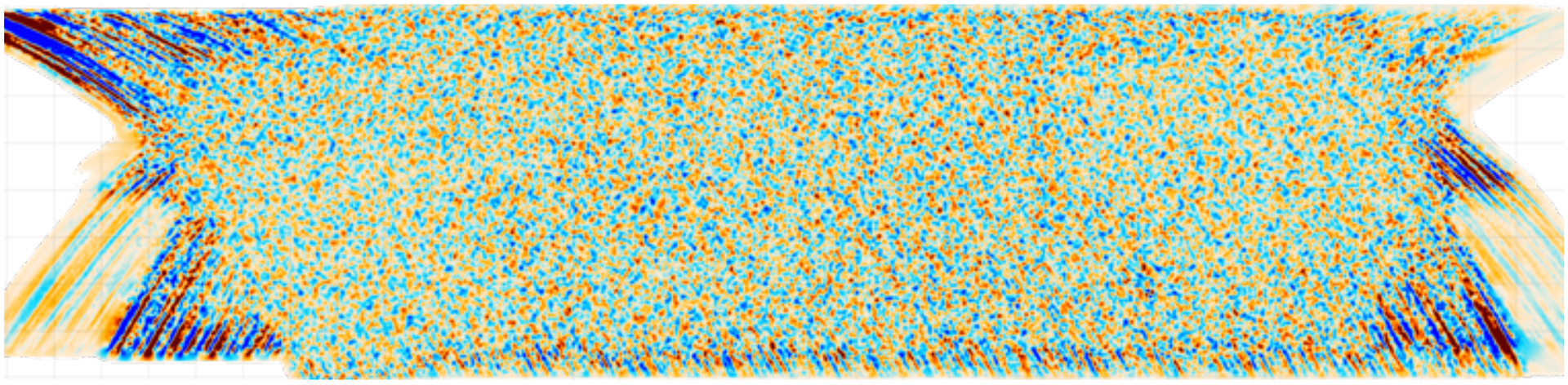


ACTPol maps

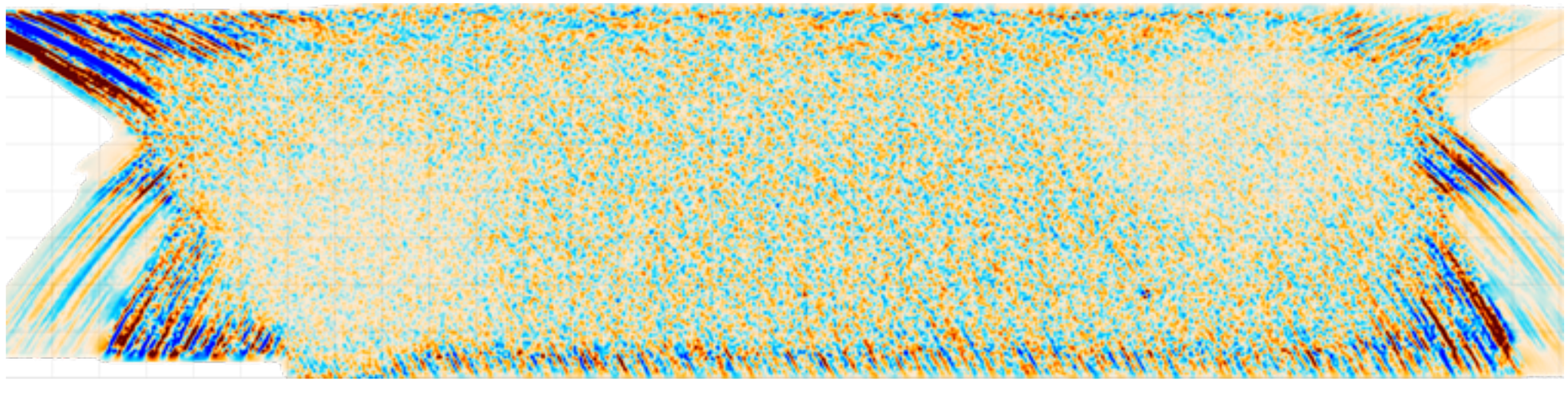
Noise Levels



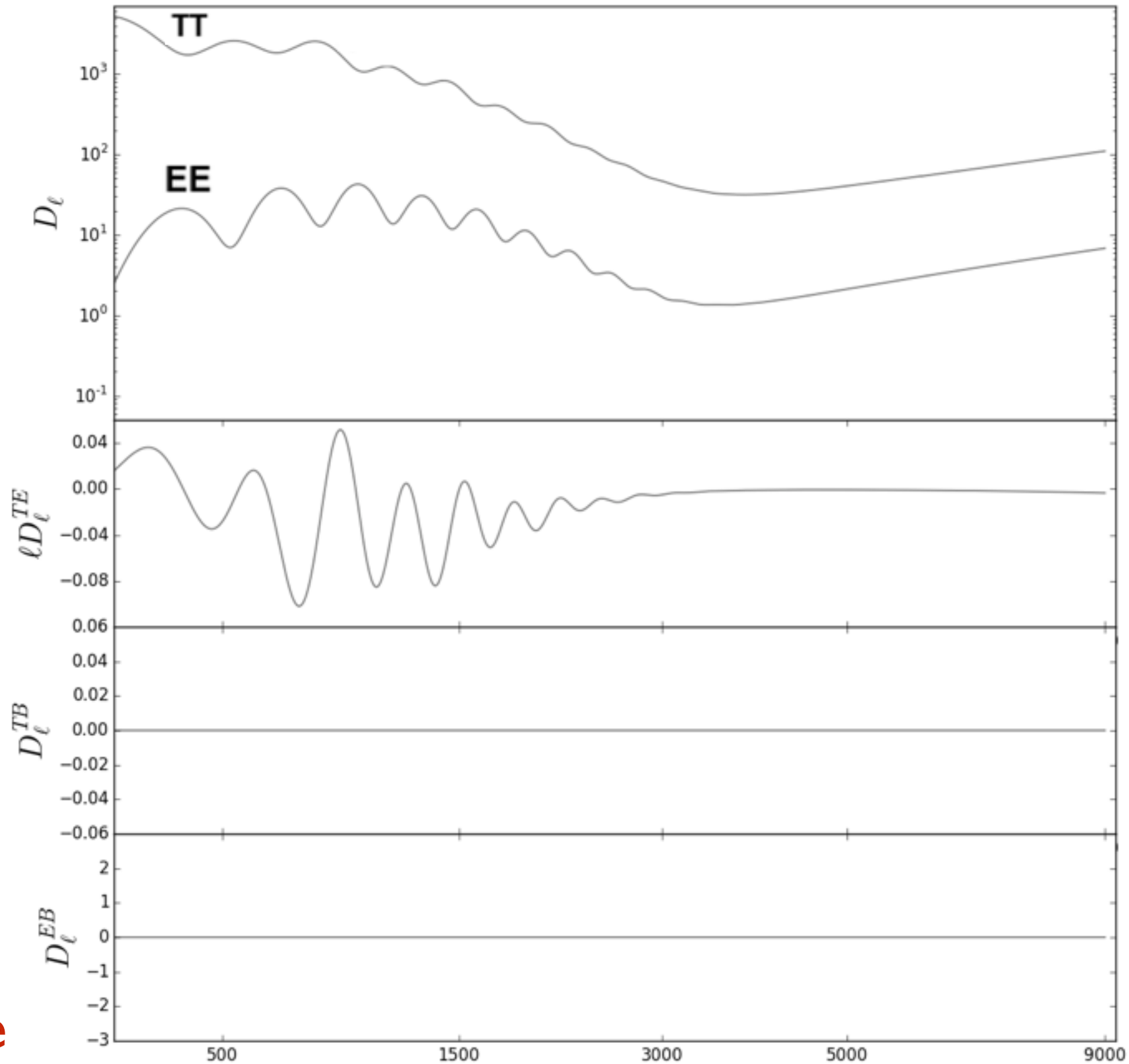
E



B

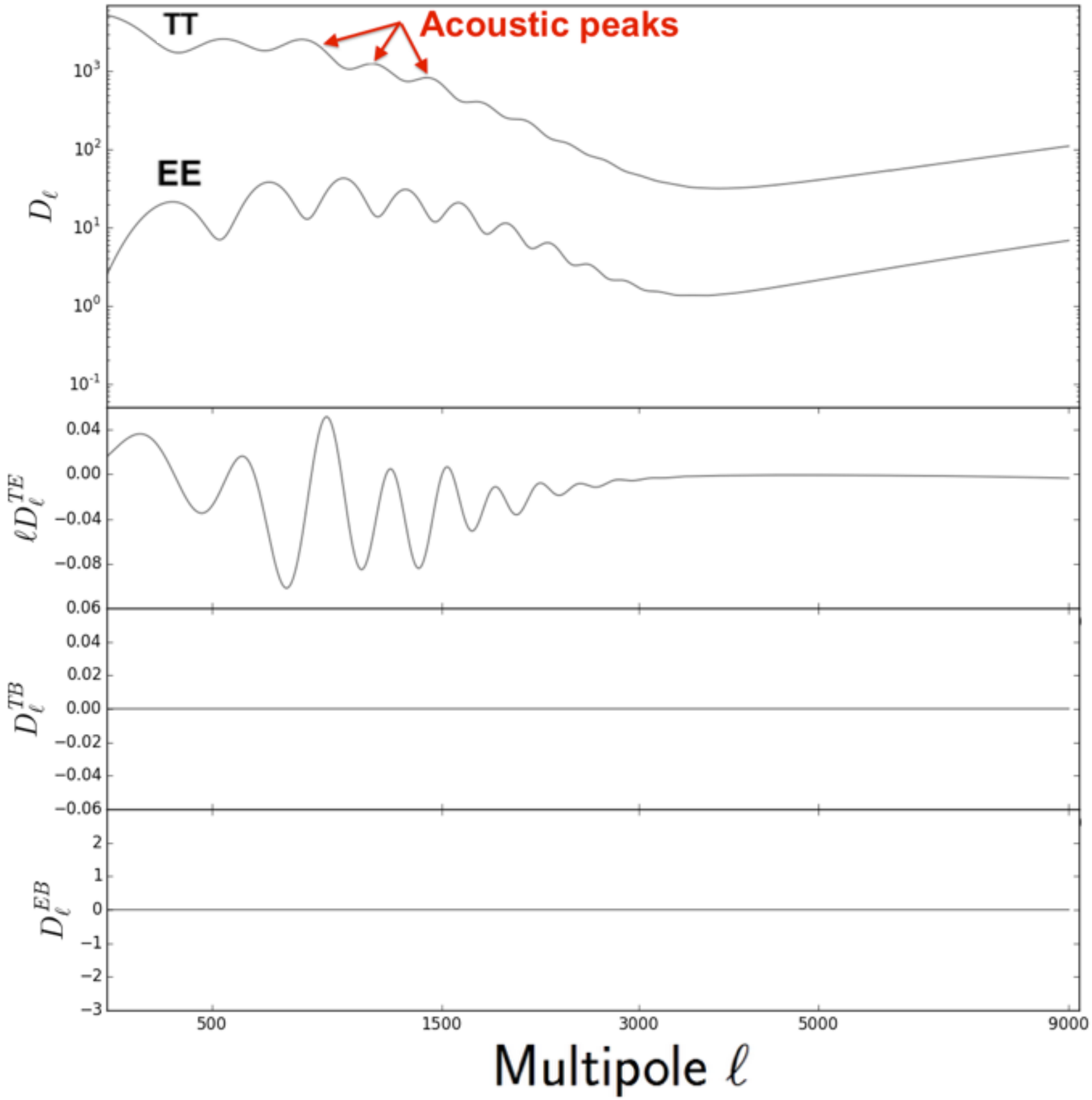


Power spectra

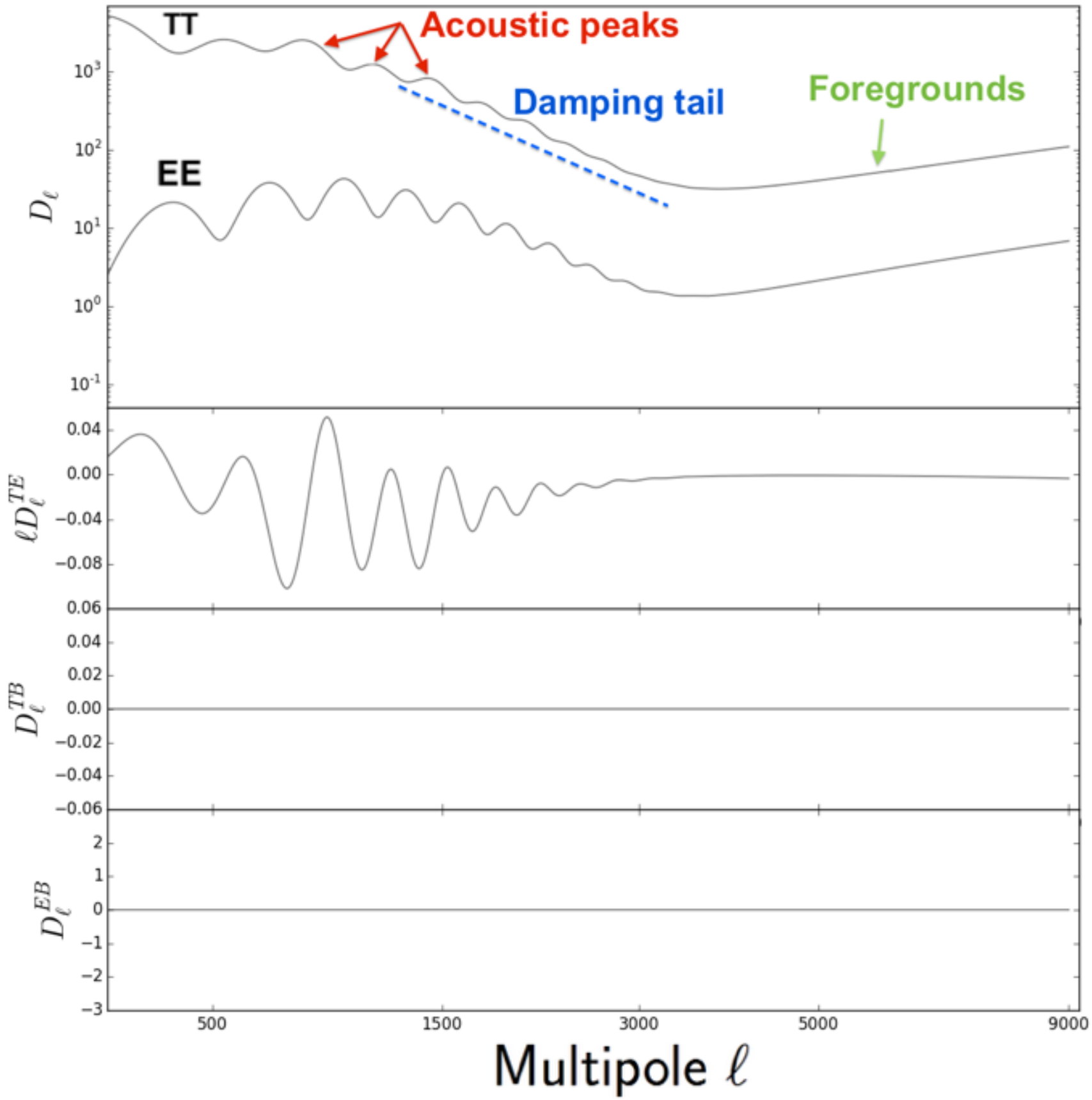


large scales ← Multipole ℓ → small scales

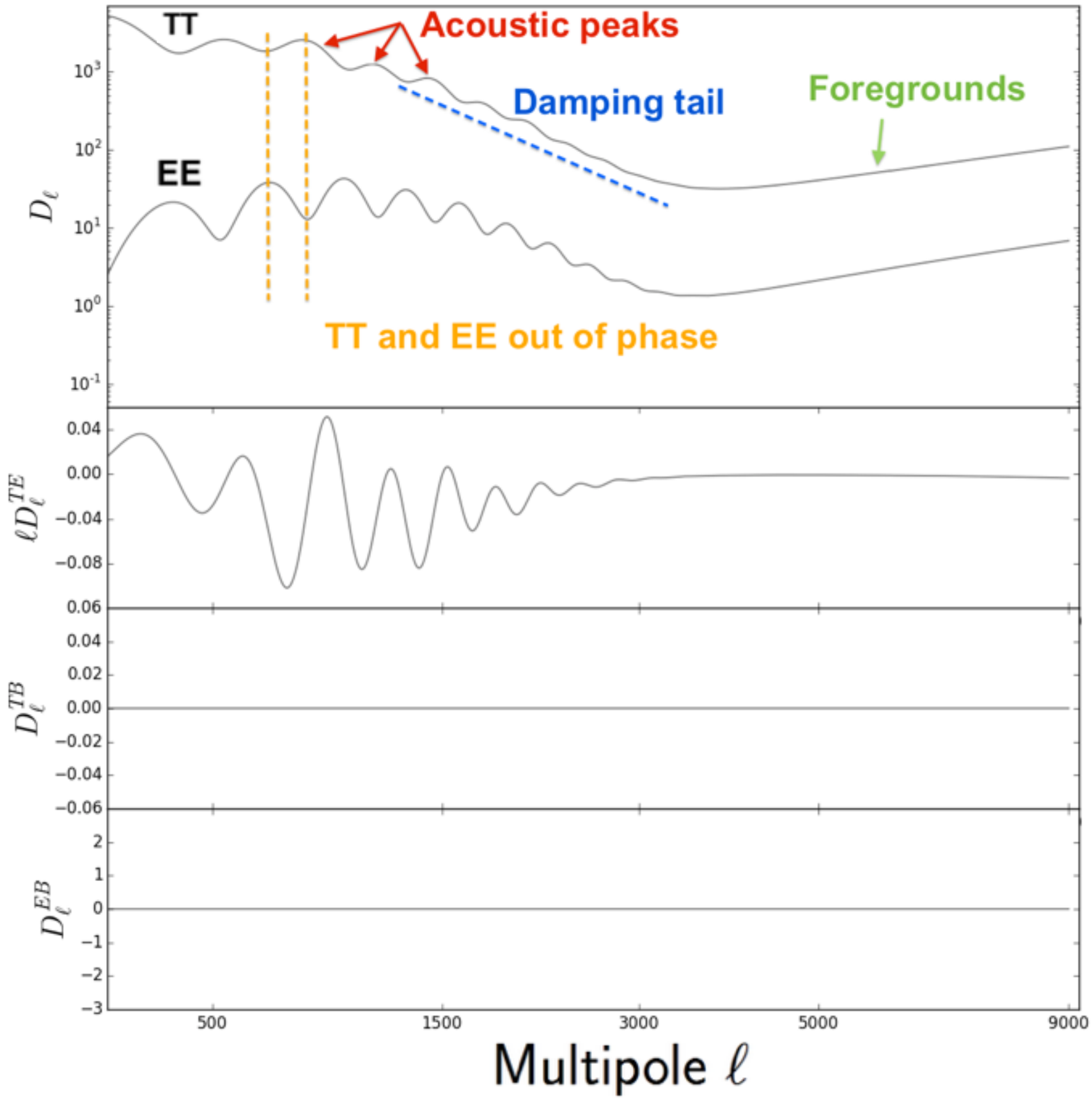
Power spectra



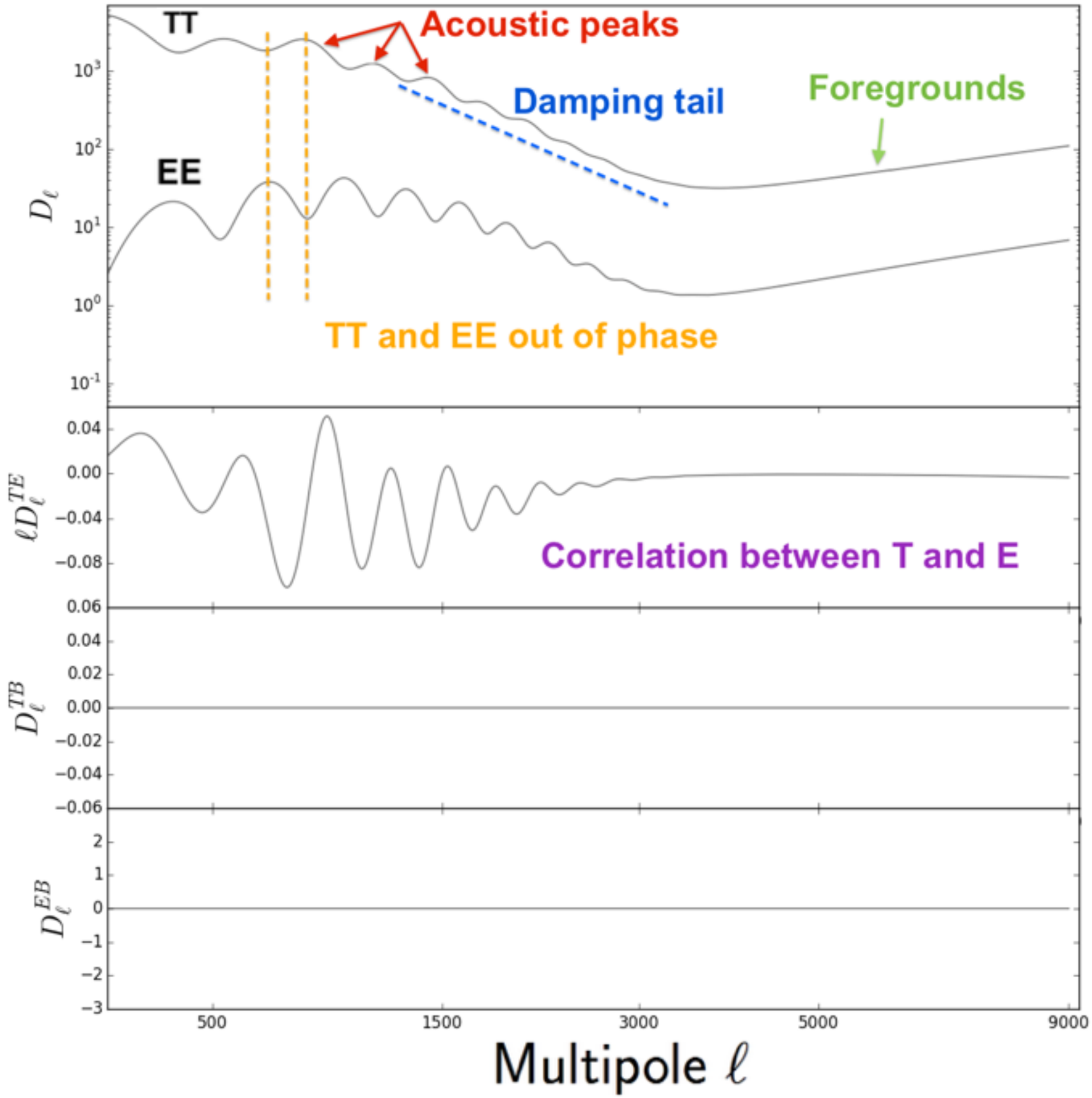
Power spectra



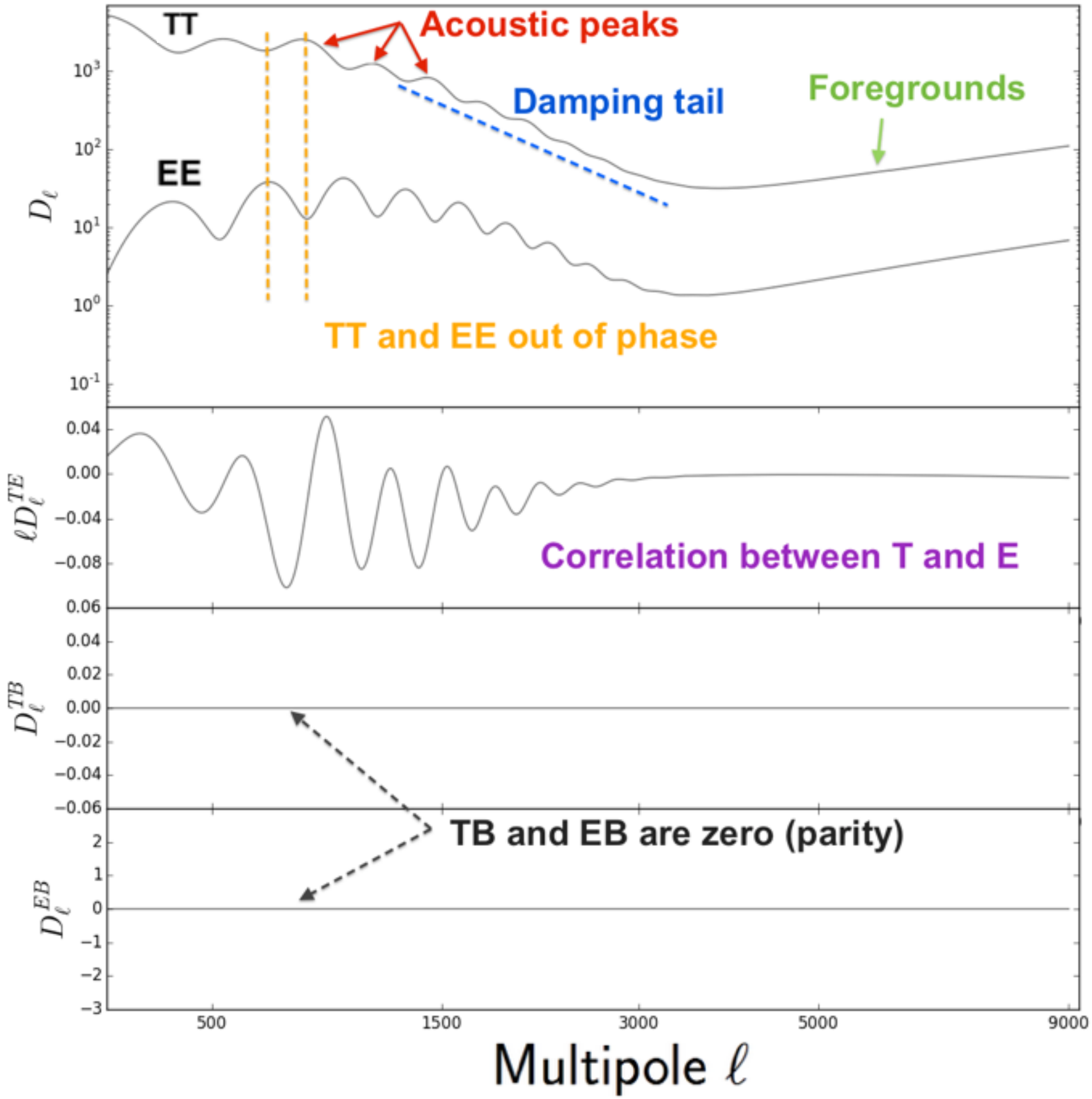
Power spectra



Power spectra

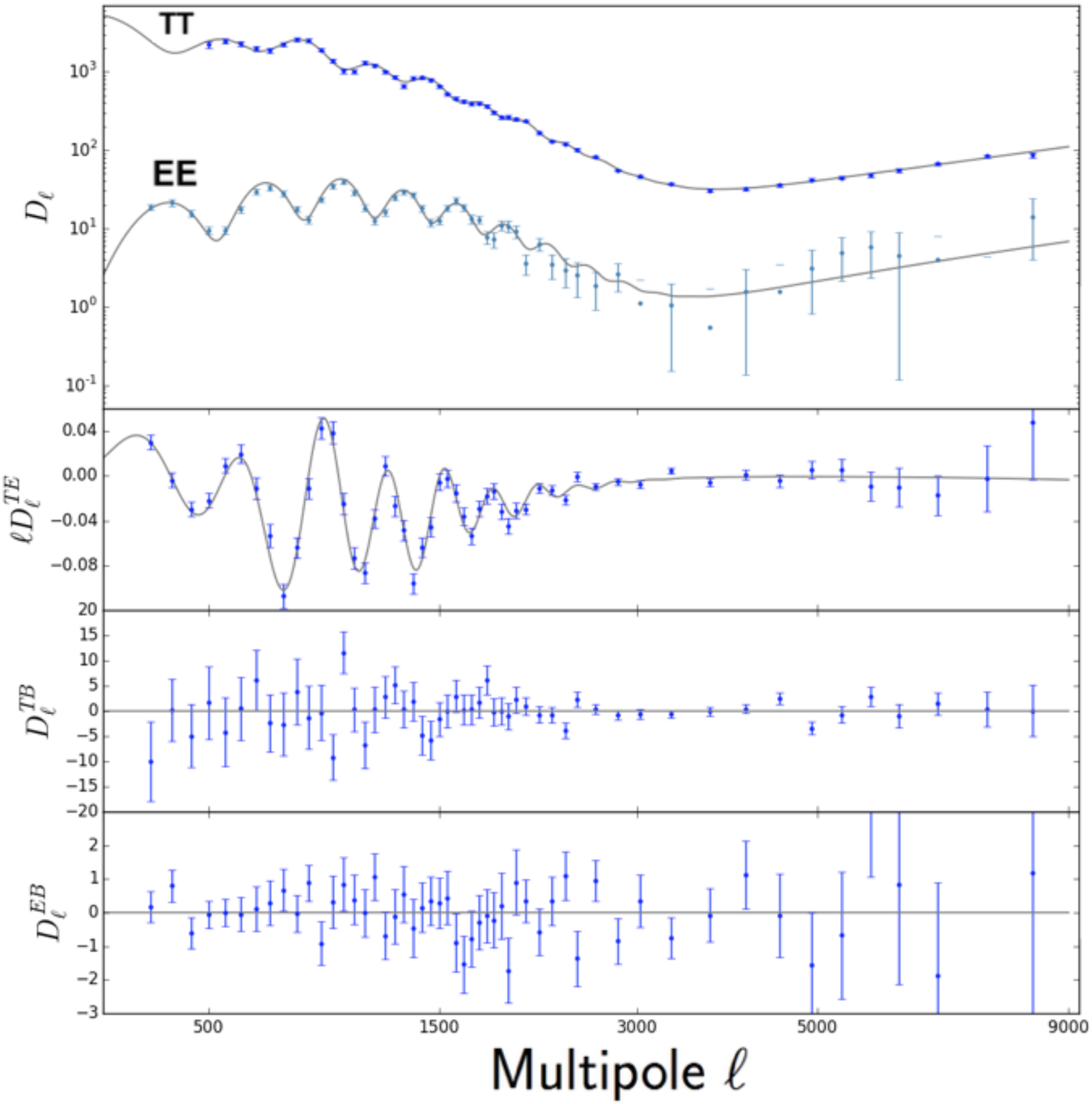


Power spectra

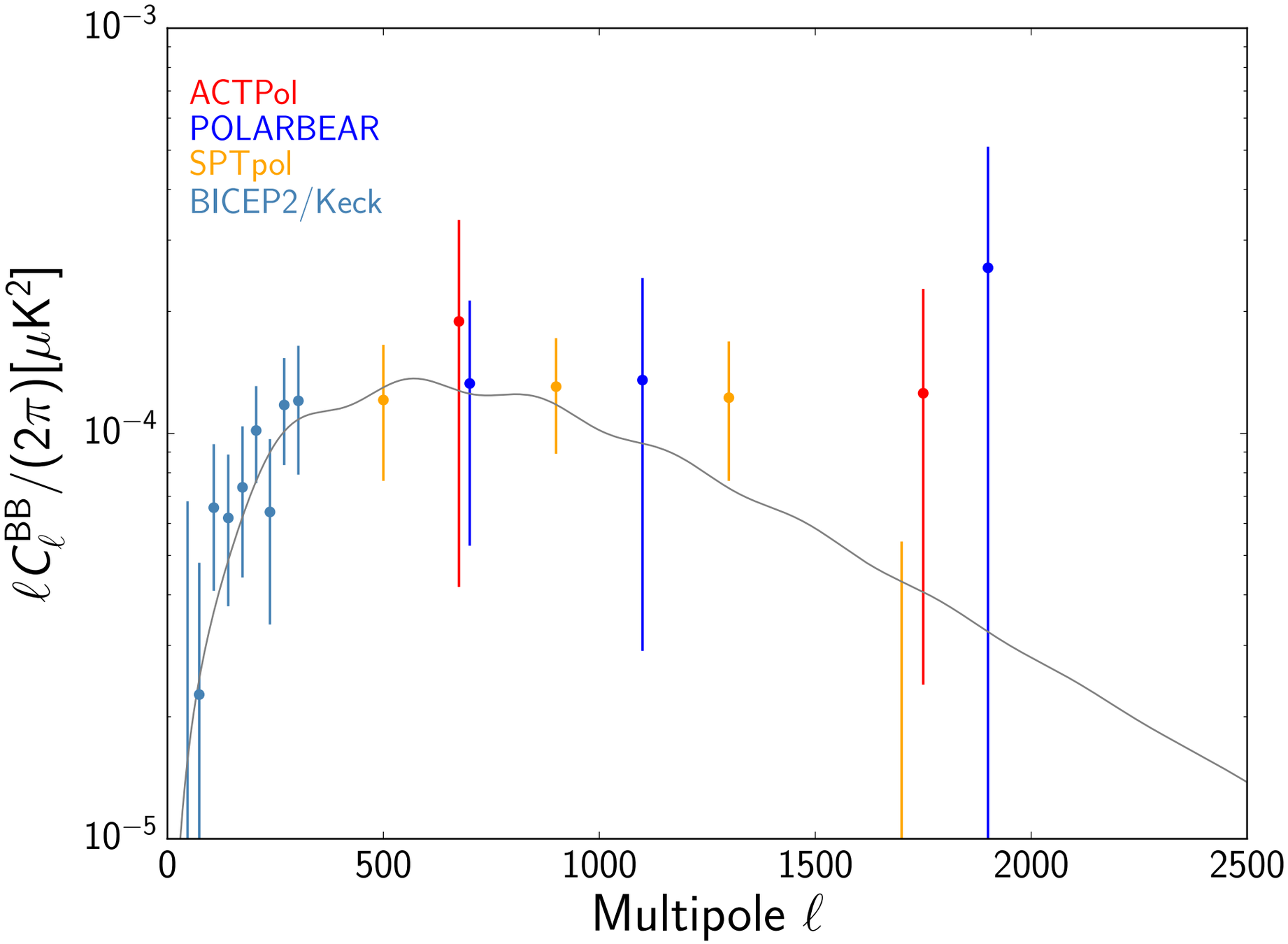


Power spectra

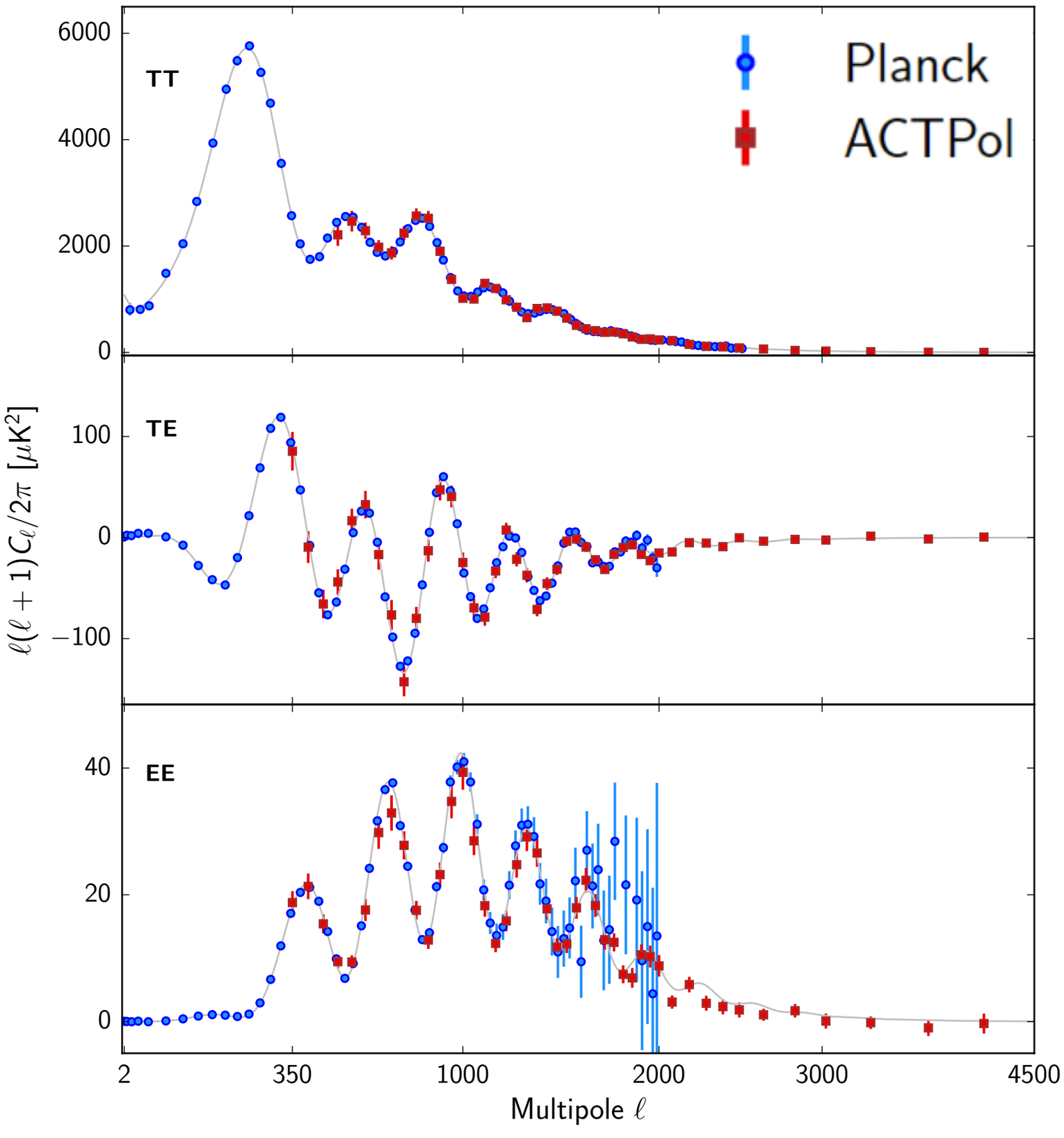
(Louis et al 2016)



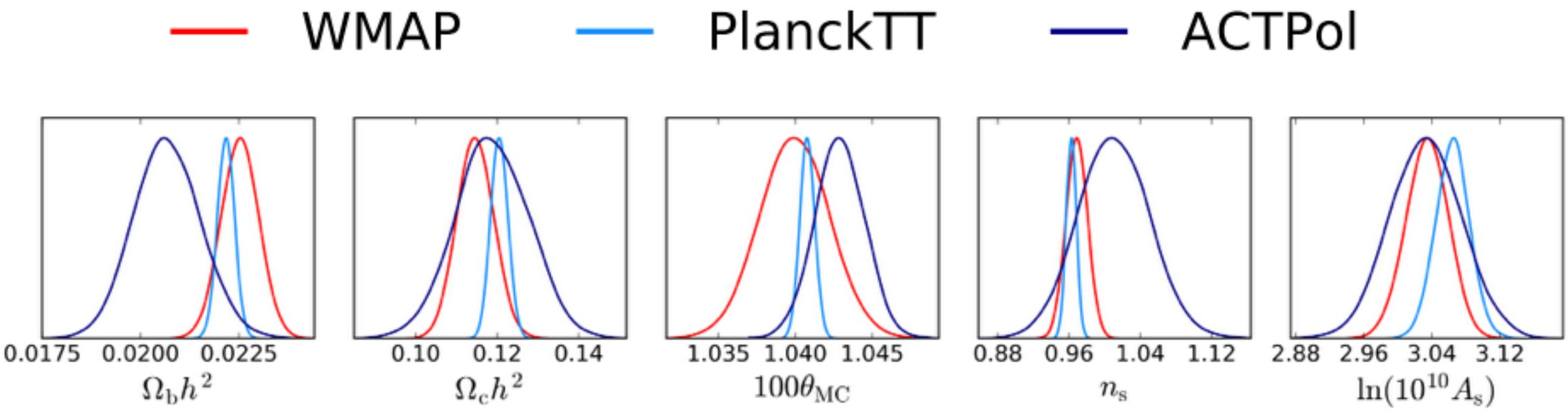
Lensed B modes

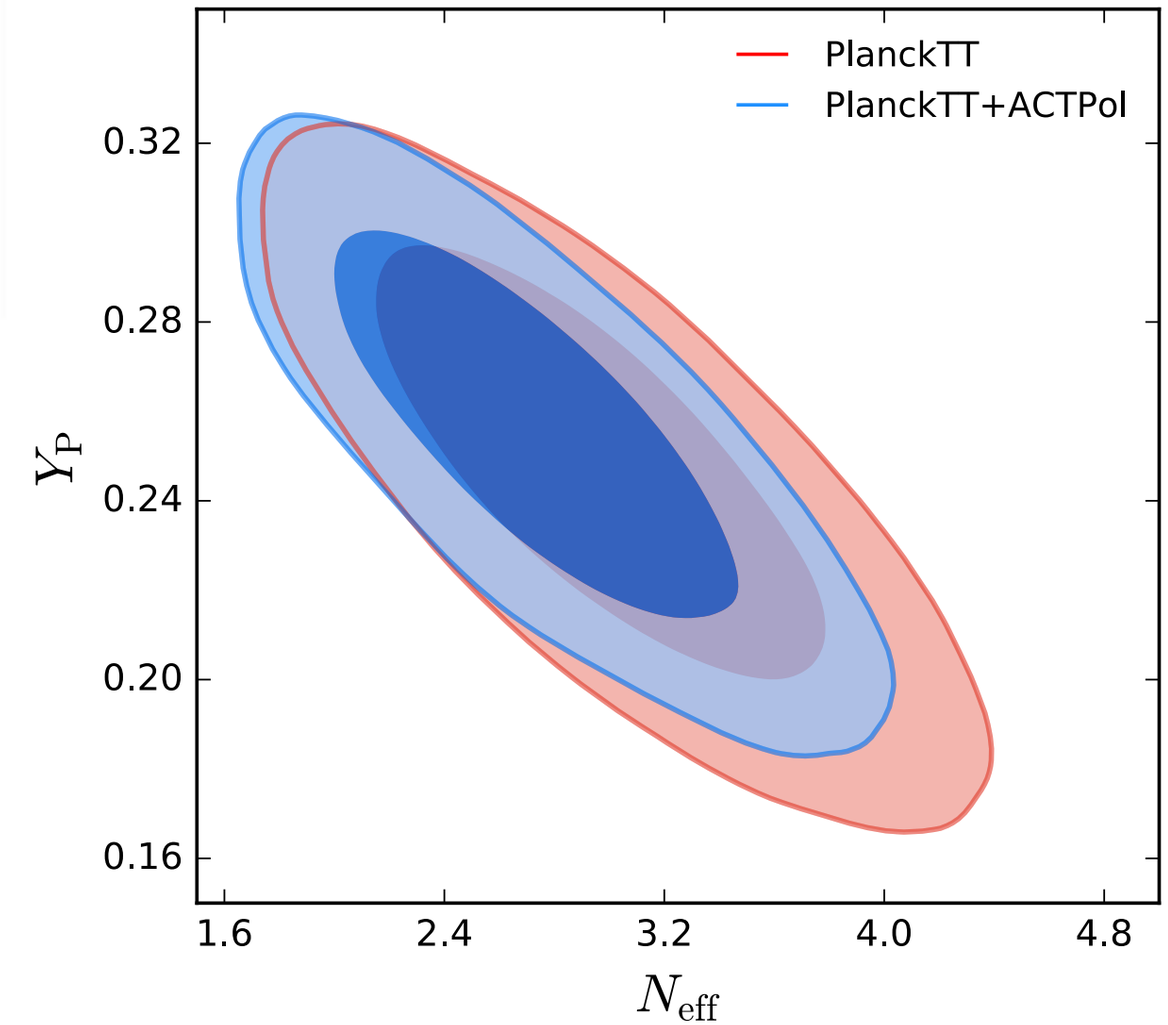


ACTPol and Planck



Parameters

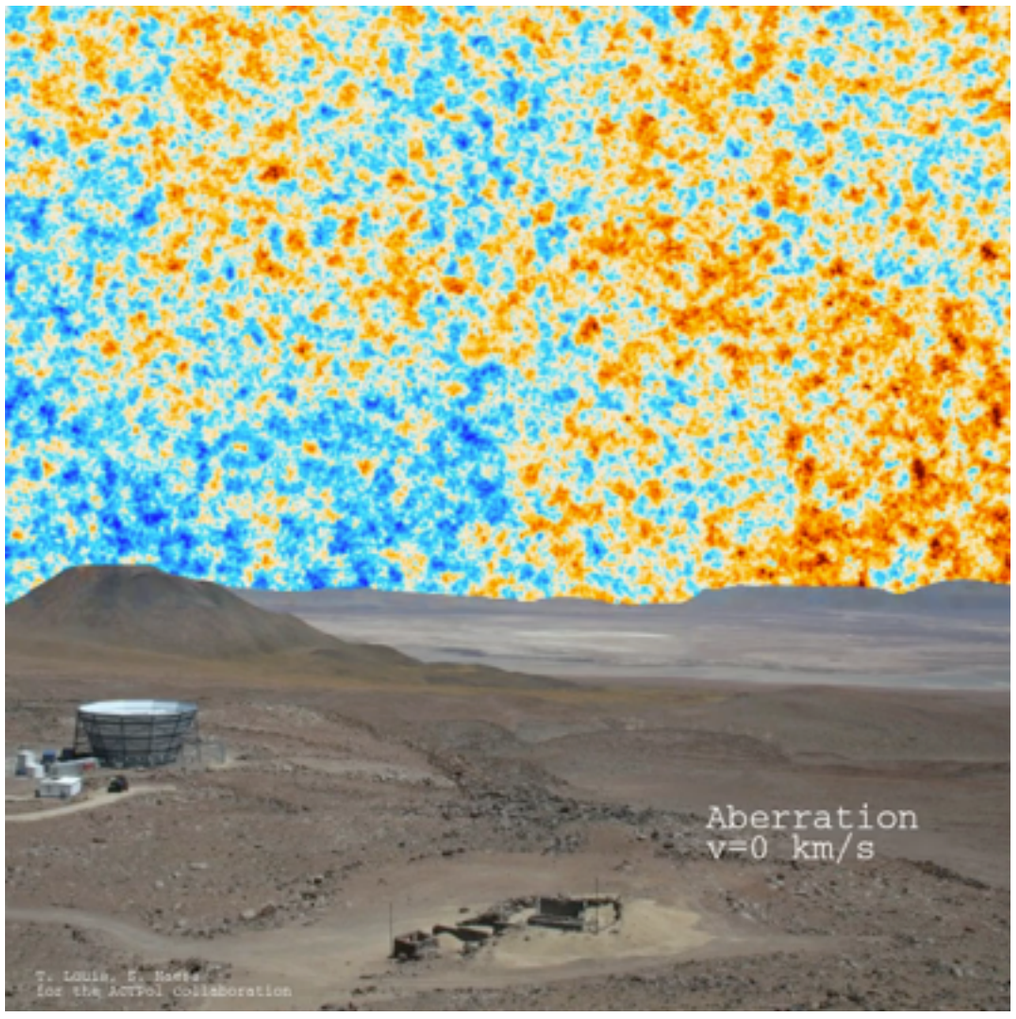

WMAP
PlanckTT
ACTPol
0.0175 0.0200 0.0225
$\Omega_{\rm b}h^2$
0.10 0.12 0.14
$\Omega_{\rm c}h^2$
1.035 1.040 1.045
$100\theta_{\rm MC}$
0.88 0.96 1.04 1.12
$n_{\rm s}$
2.88 2.96 3.04 3.12
$\ln(10^{10}A_{\rm s})$


PlanckTT
PlanckTT+ACTPol
0.32
0.28
0.24
0.20
0.16
$Y_{\rm P}$
1.6
2.4
3.2
4.0
4.8
$N_{\rm eff}$

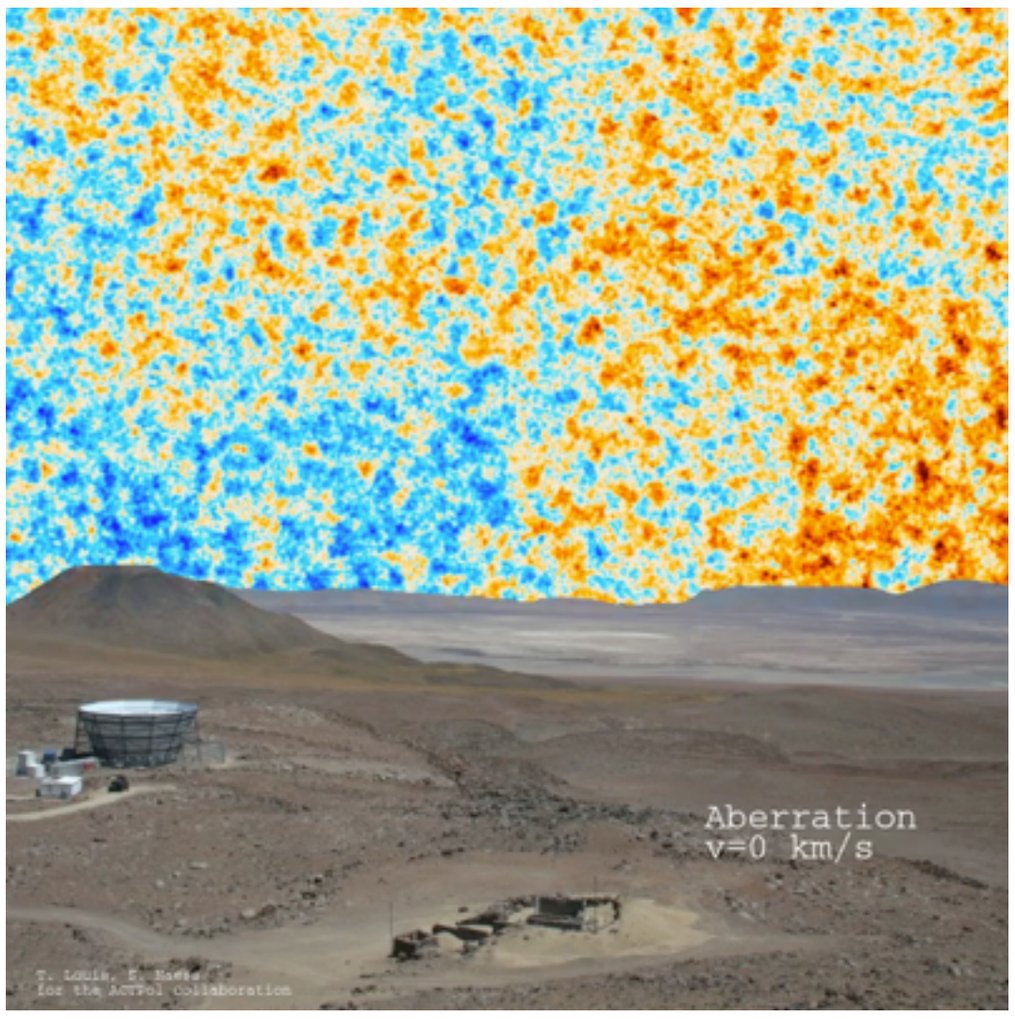
Aberration

We are moving with respect to the last scattering surface, at a speed v=369 km/s

looking forward

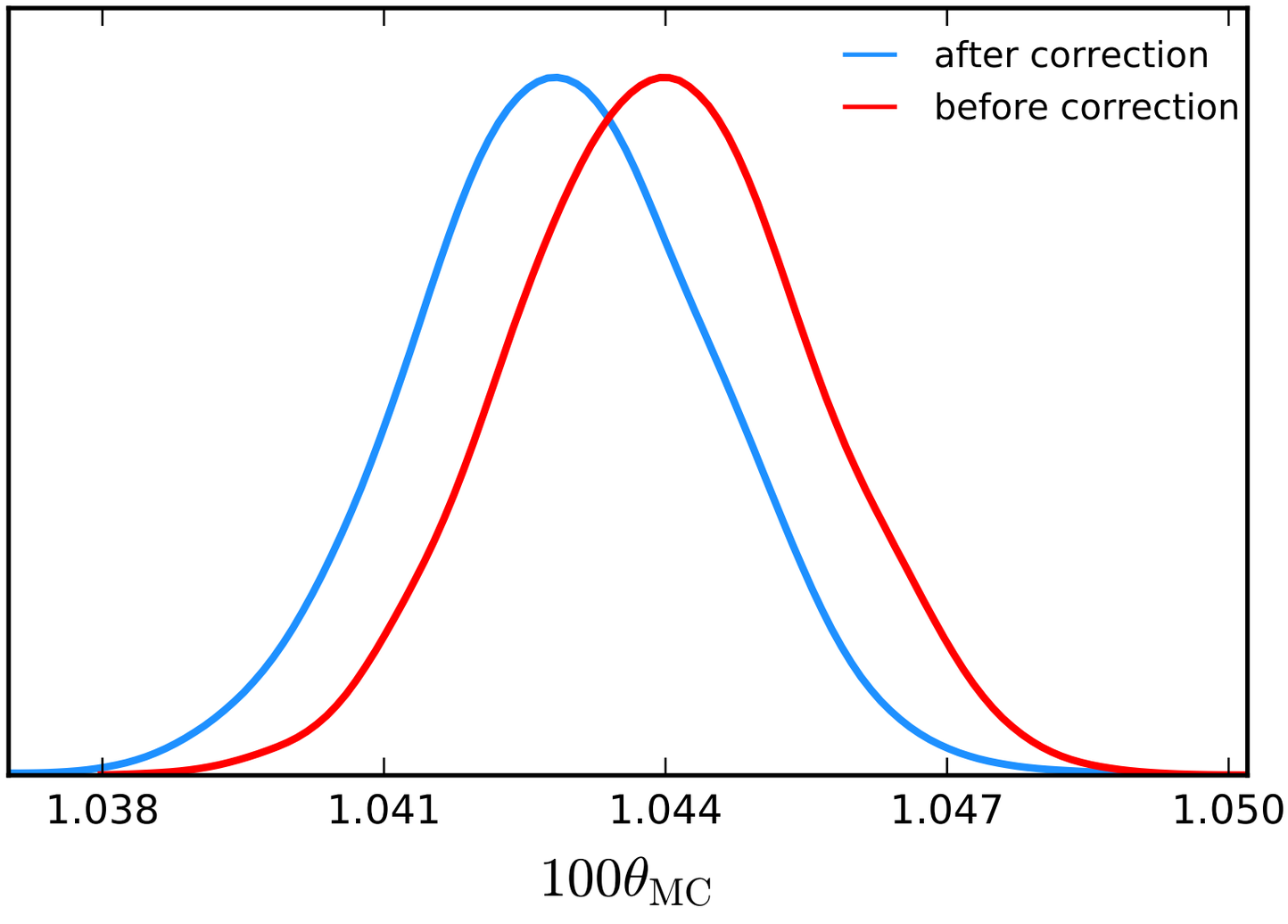


looking backward



Aberration

This motion produces a bias in the cosmological parameter theta and need to be corrected



What's next?

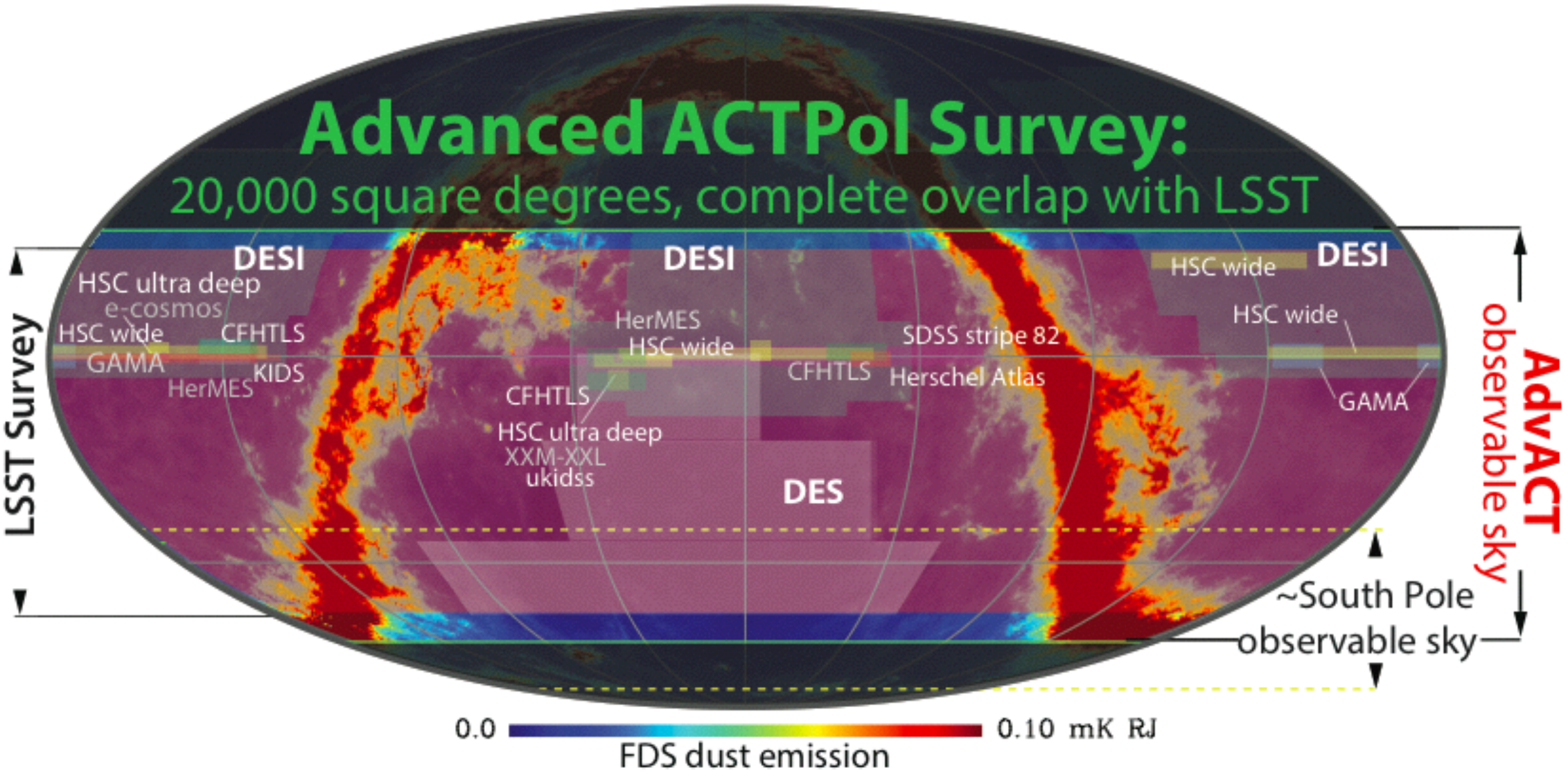
This analysis includes only 12% of the full three-season ACTPol data taken from 2013-15

Advanced ACTPol is now taking data (2016-2019)

(3 frequencies on the sky)

What's next?

Half the sky at arc minute resolution !

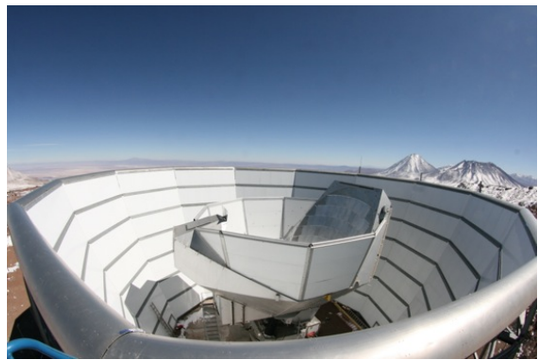


What's next?

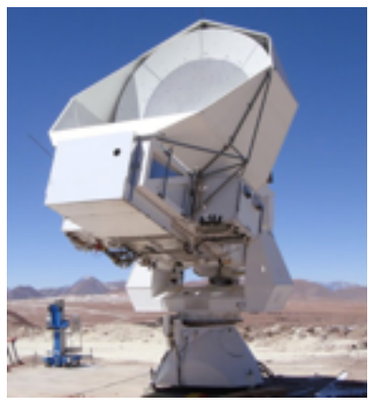
Simons observatory (2020-)

CMB S4

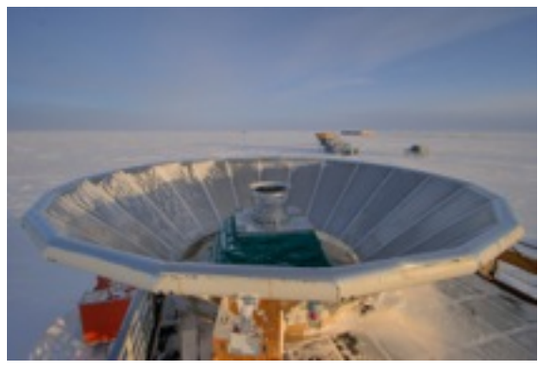
ACTPol



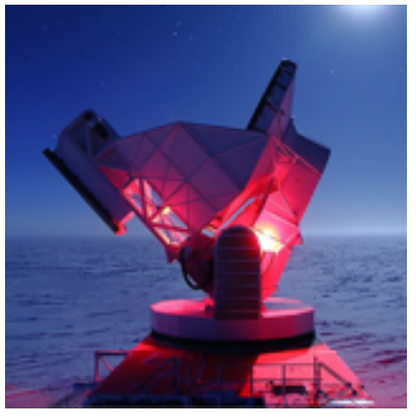
Polarbear



Bicep

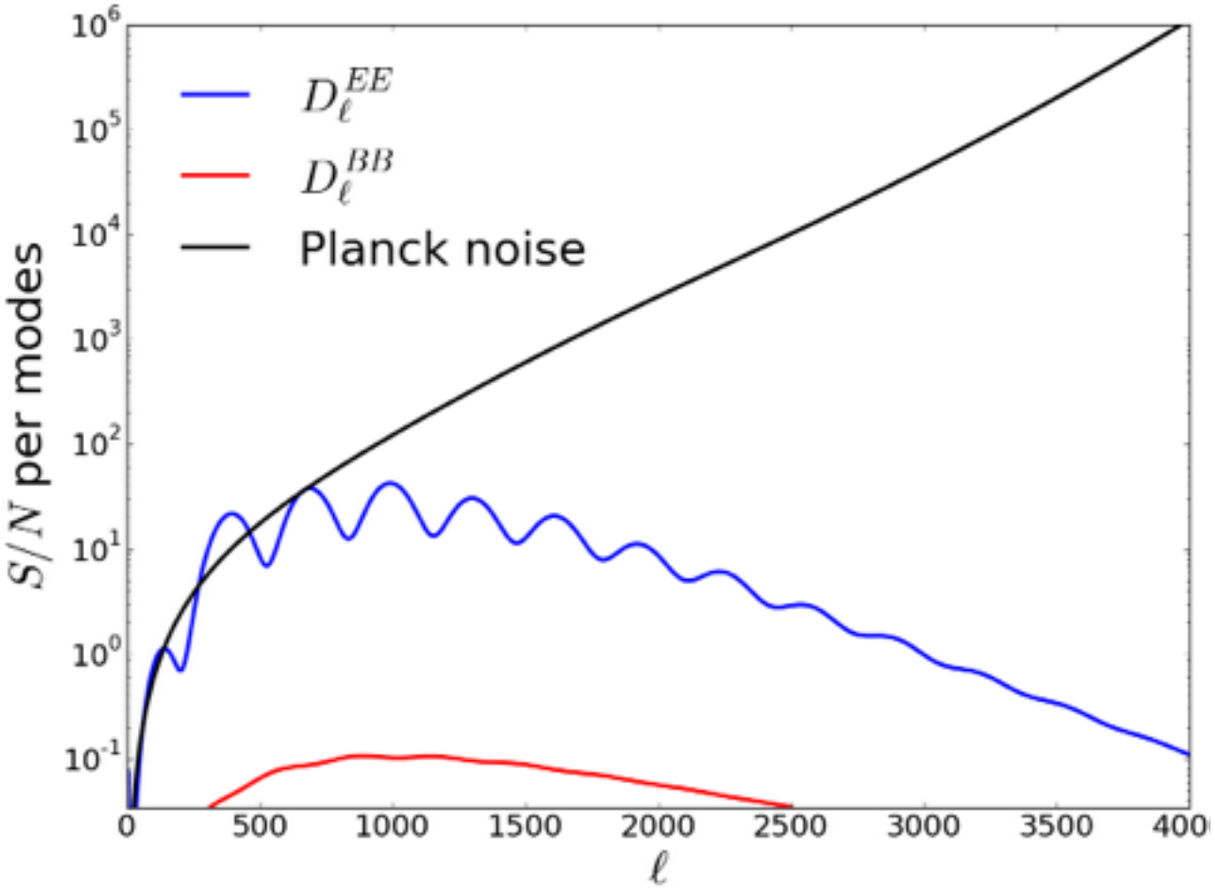


SPTpol

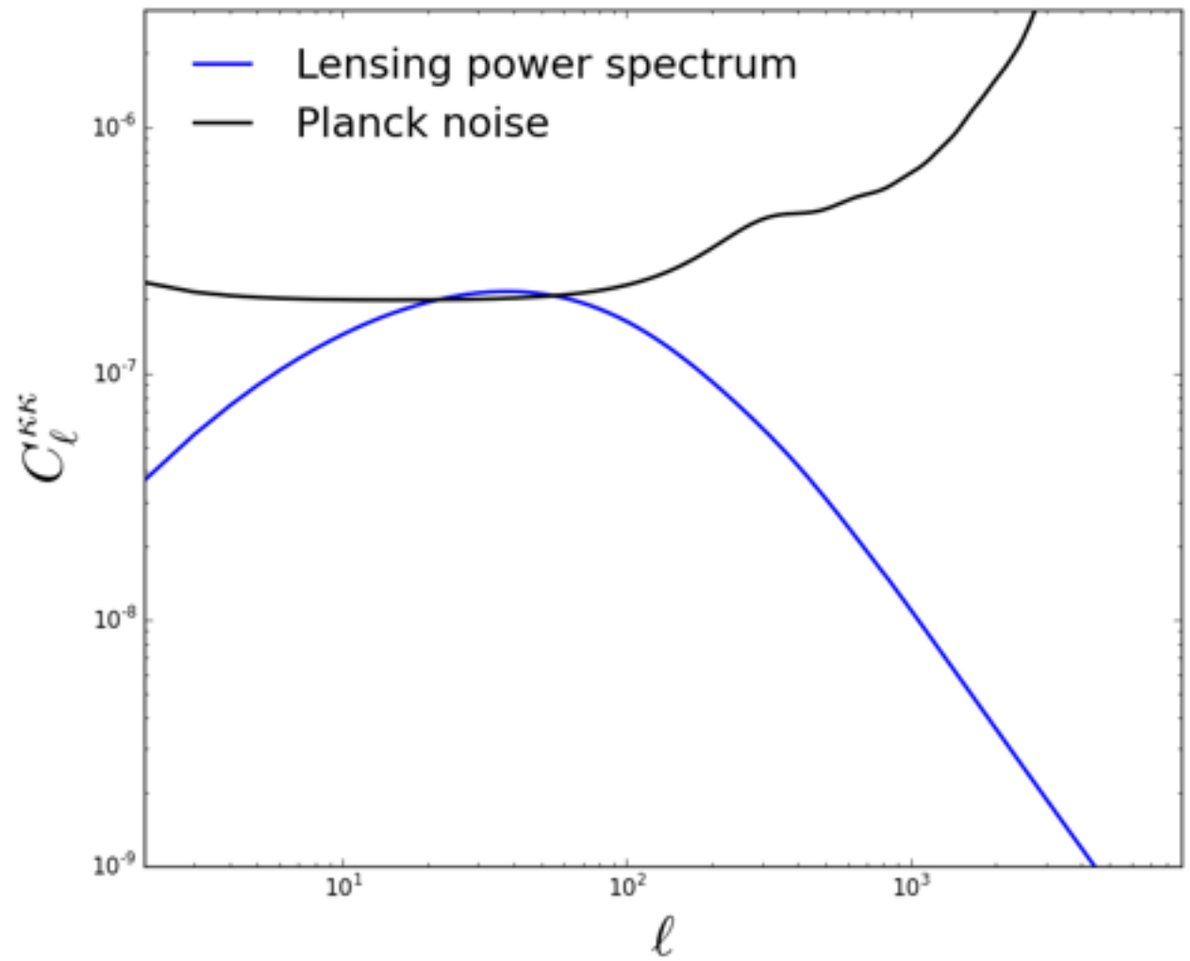


Why bother?

S/N polarisation



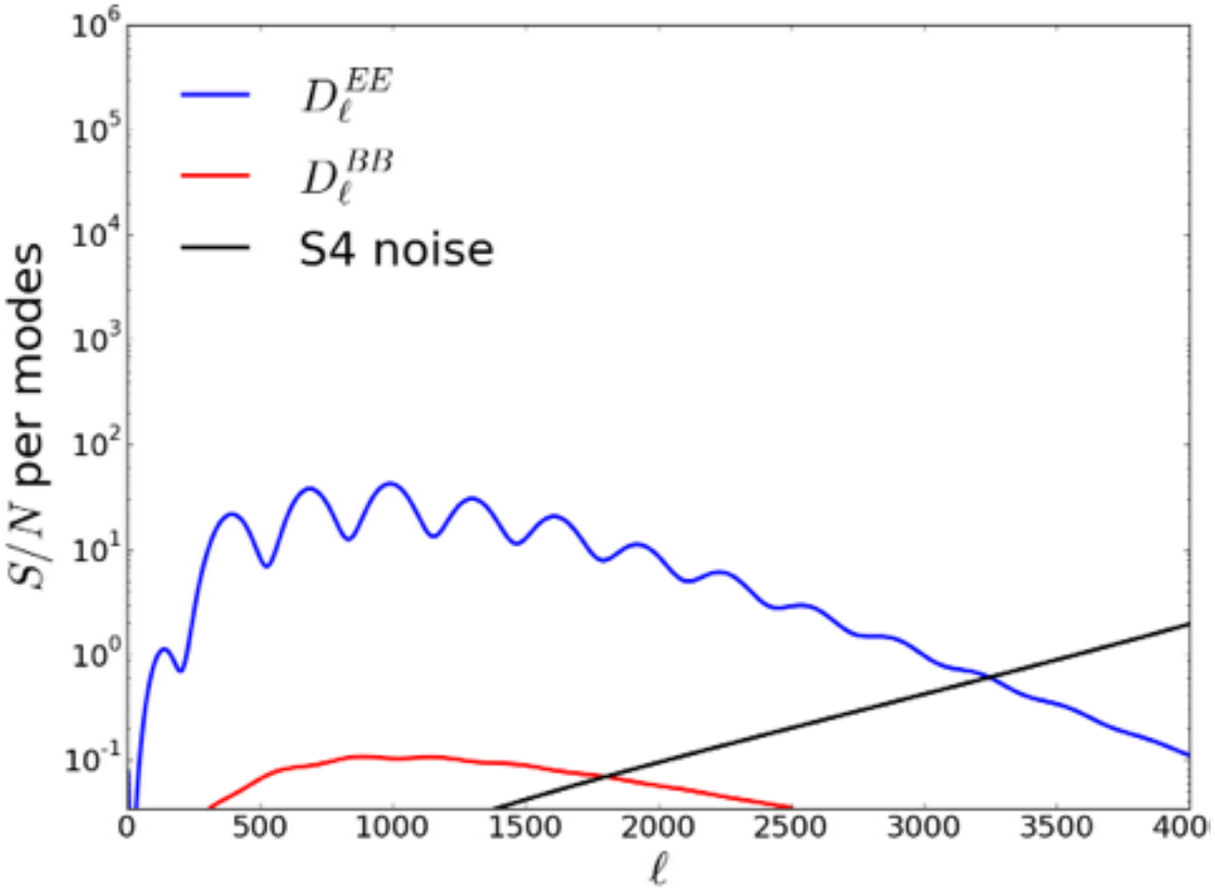
S/N lensing



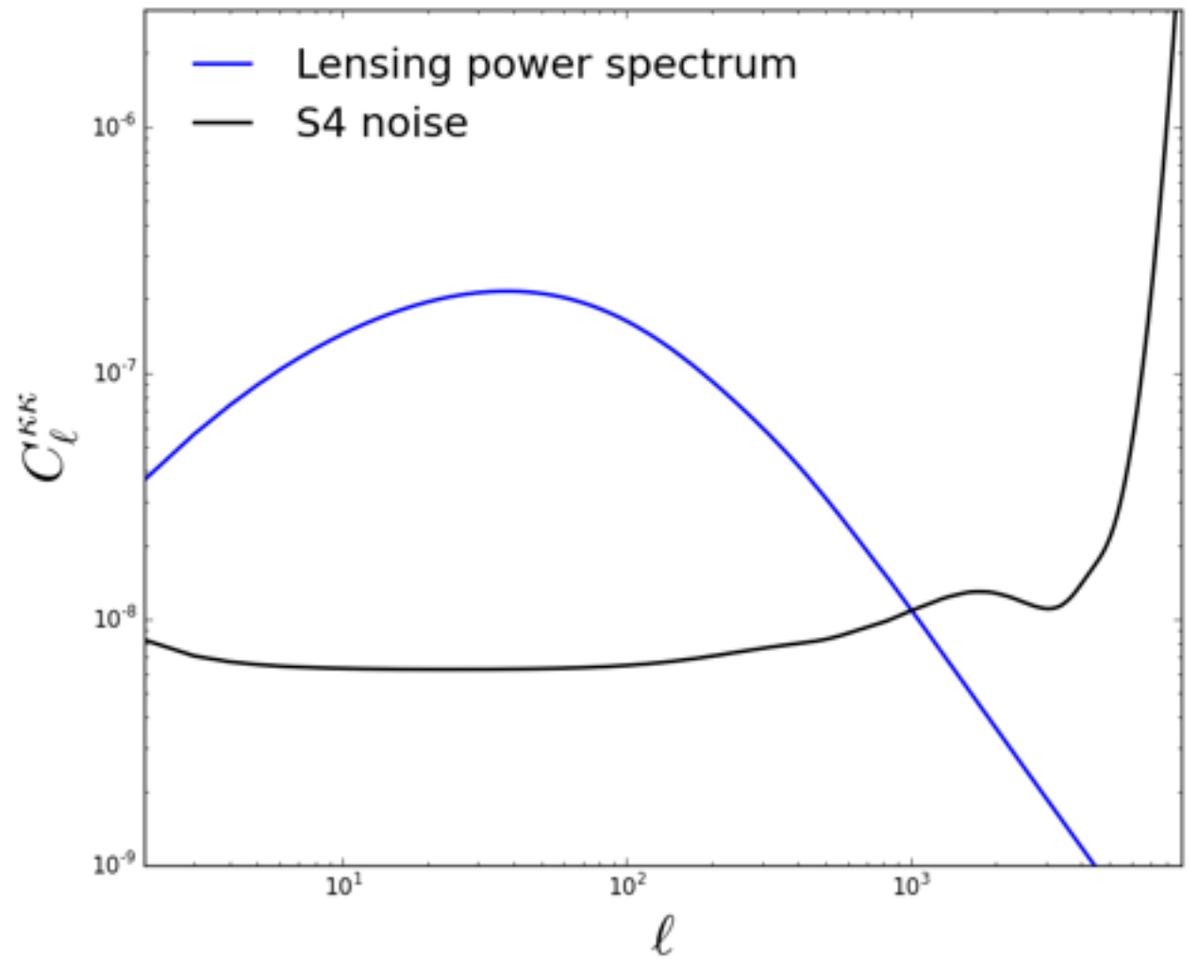
Planck is noise dominated both in polarisation and for the lensing reconstruction.

Why bother?

S/N polarisation



S/N lensing



S4 will be cosmic variance limited up to 3000 in EE and up to 1000 in the lensing potential

Some science goals

-Detection of primordial gravitational waves

Tensor to scalar ratio: $r \approx 10^{-3}$

-Detection of the sum of neutrinos masses

S4+ DESI (BAO), 5 sigma detection of $\sum m_\nu = 60$ meV

Some science goals

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-.....

-.....

Some science goals

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Tensor to scalar ratio: $r \approx 10^{-3}$

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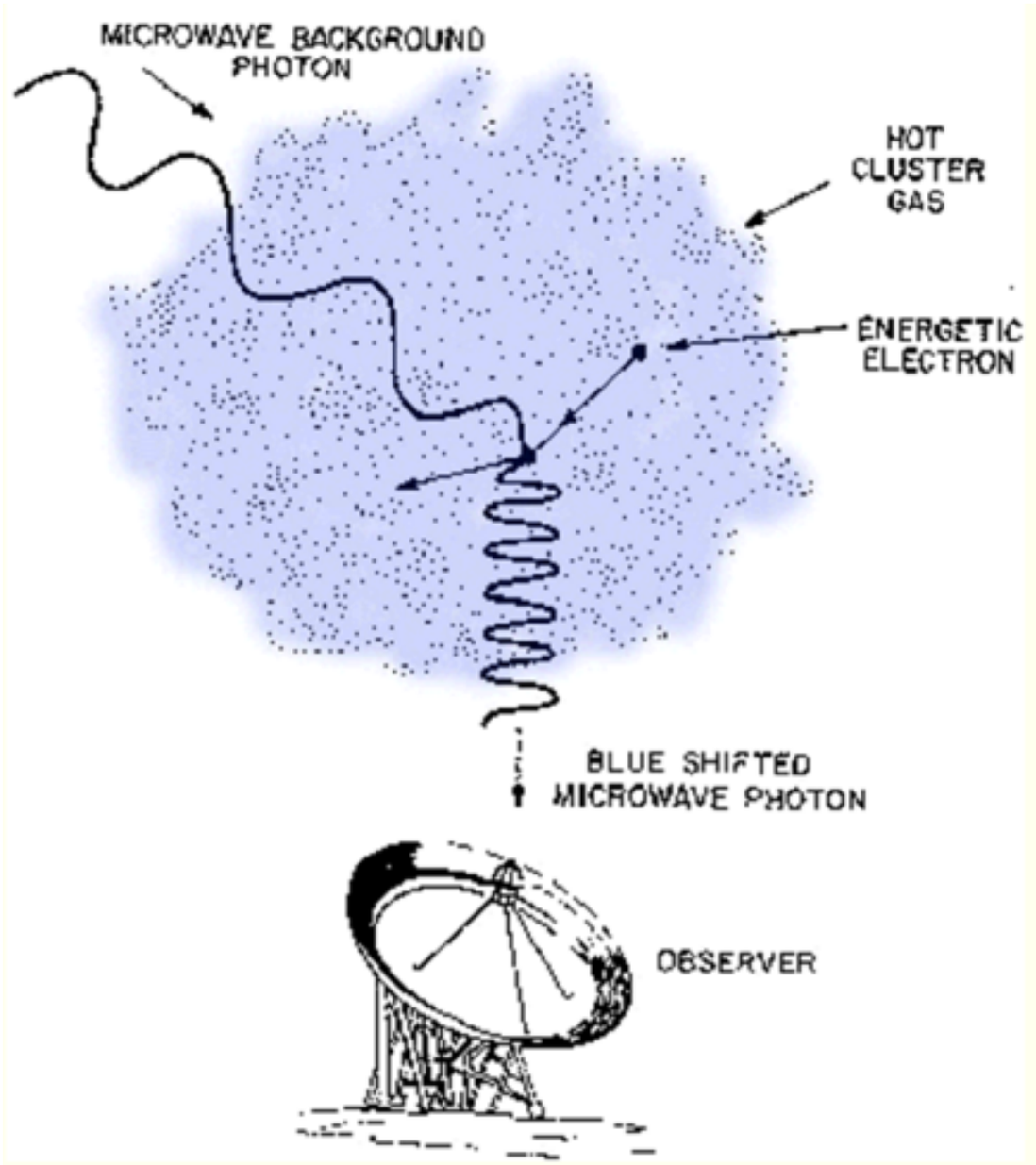
S4+ DESI (BAO), 5 sigma detection of $\sum m_\nu = 60$ meV

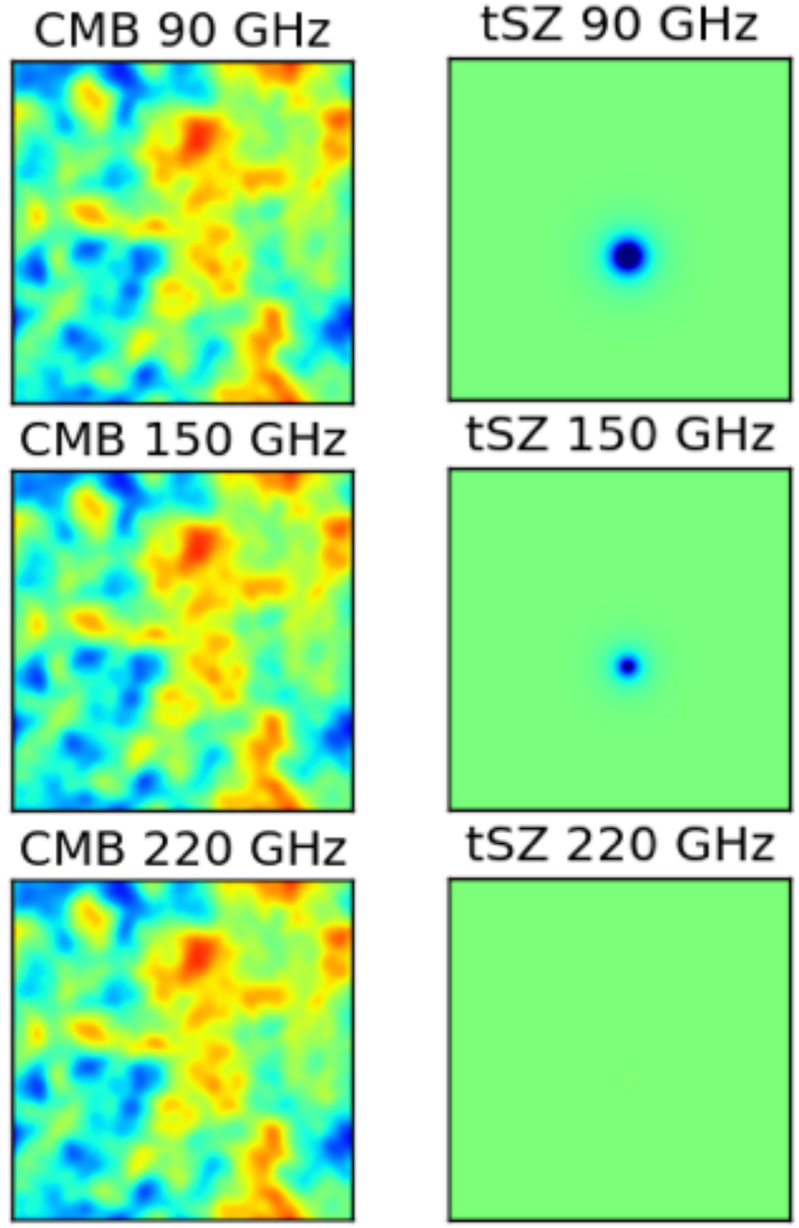
-.....

-.....

-Detection of the 100 000 most massive clusters in the south hemisphere

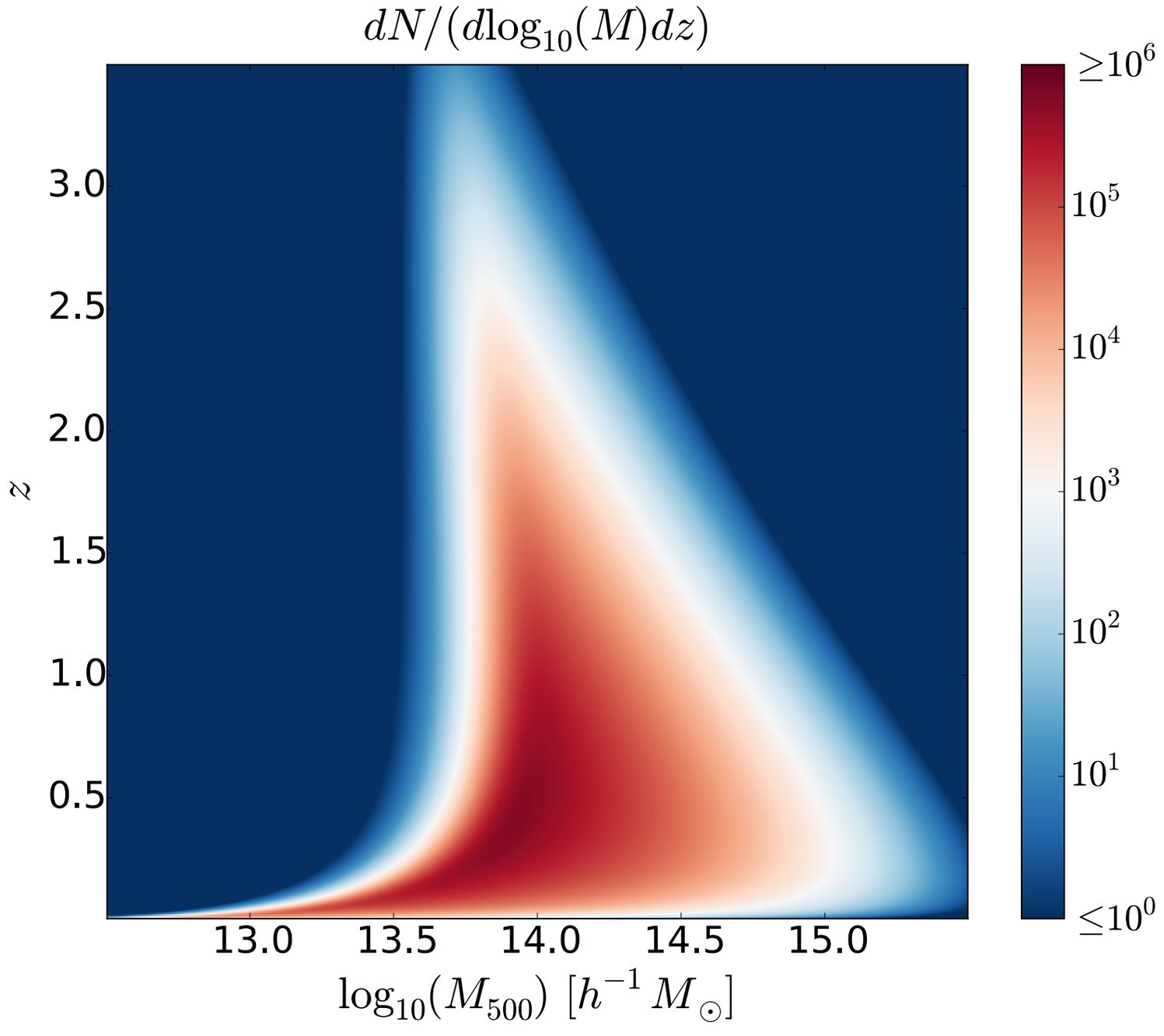
tSZ effect


MICROWAVE BACKGROUND PHOTON
HOT CLUSTER GAS
ENERGETIC ELECTRON
BLUE SHIFTED MICROWAVE PHOTON
OBSERVER


CMB 90 GHz
tSZ 90 GHz
CMB 150 GHz
tSZ 150 GHz
CMB 220 GHz
tSZ 220 GHz

Cluster distribution

The number of cluster as a function of mass and redshift is a prediction of the LCDM model



Cluster distribution

We observe the tSZ flux, it is correlated with the mass of the observed clusters

$$\left.\frac{\Delta \mathrm{T}}{\mathrm{T}}\right|_{\mathrm{tSZ}}(\nu, \hat{\mathbf{n}}) = f_{\mathrm{tSZ}}(\nu)\frac{\sigma_T}{m_e c^2}\int P_e(l, \hat{\mathbf{n}})dl$$
$$\equiv f_{\mathrm{tSZ}}(\nu)\, Y(\hat{\mathbf{n}})$$

The exact relationship between Y and M is currently calibrated using X-ray observation of clusters.

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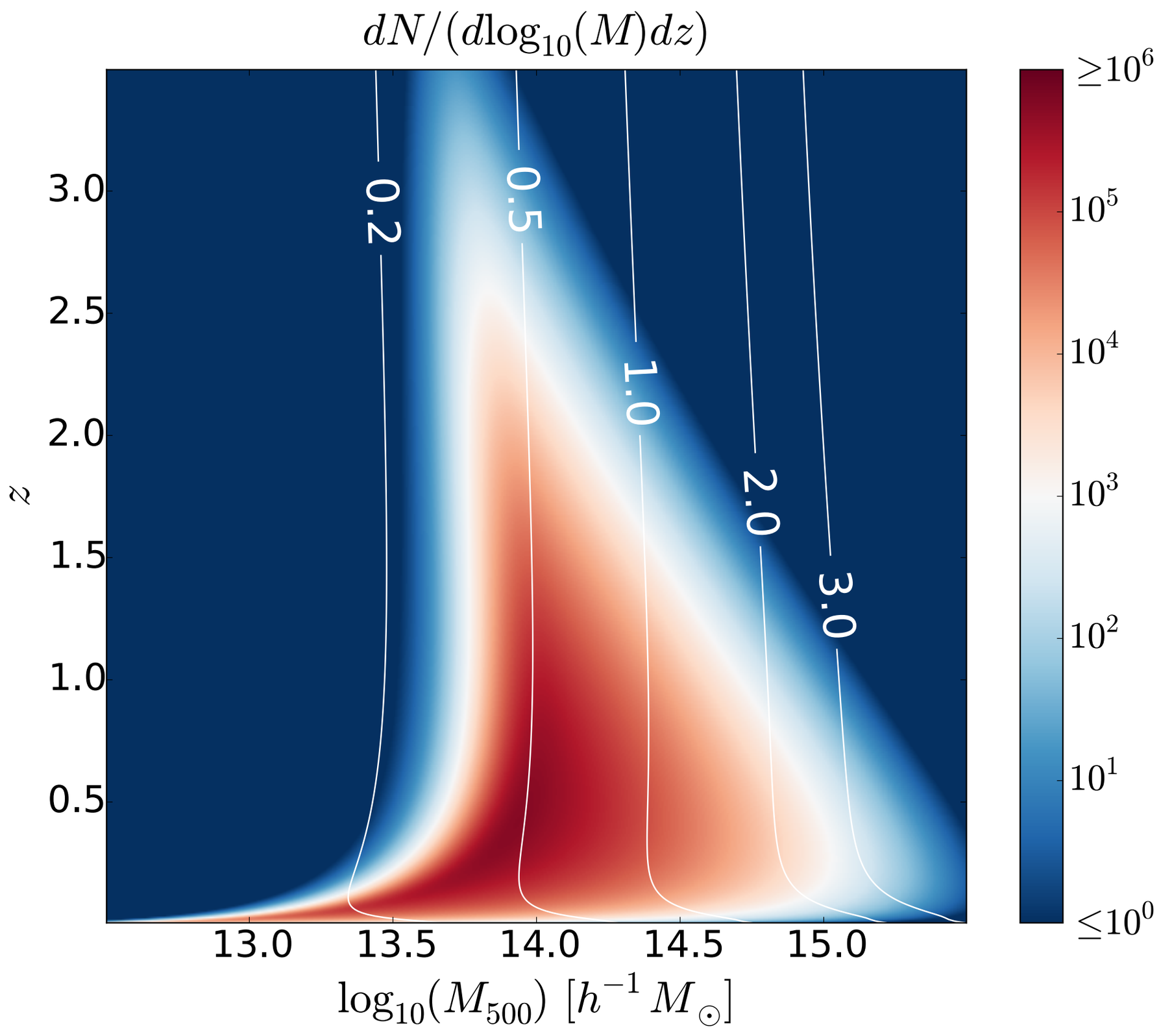
The exact relationship between Y and M is currently calibrated using X-ray observation of clusters.

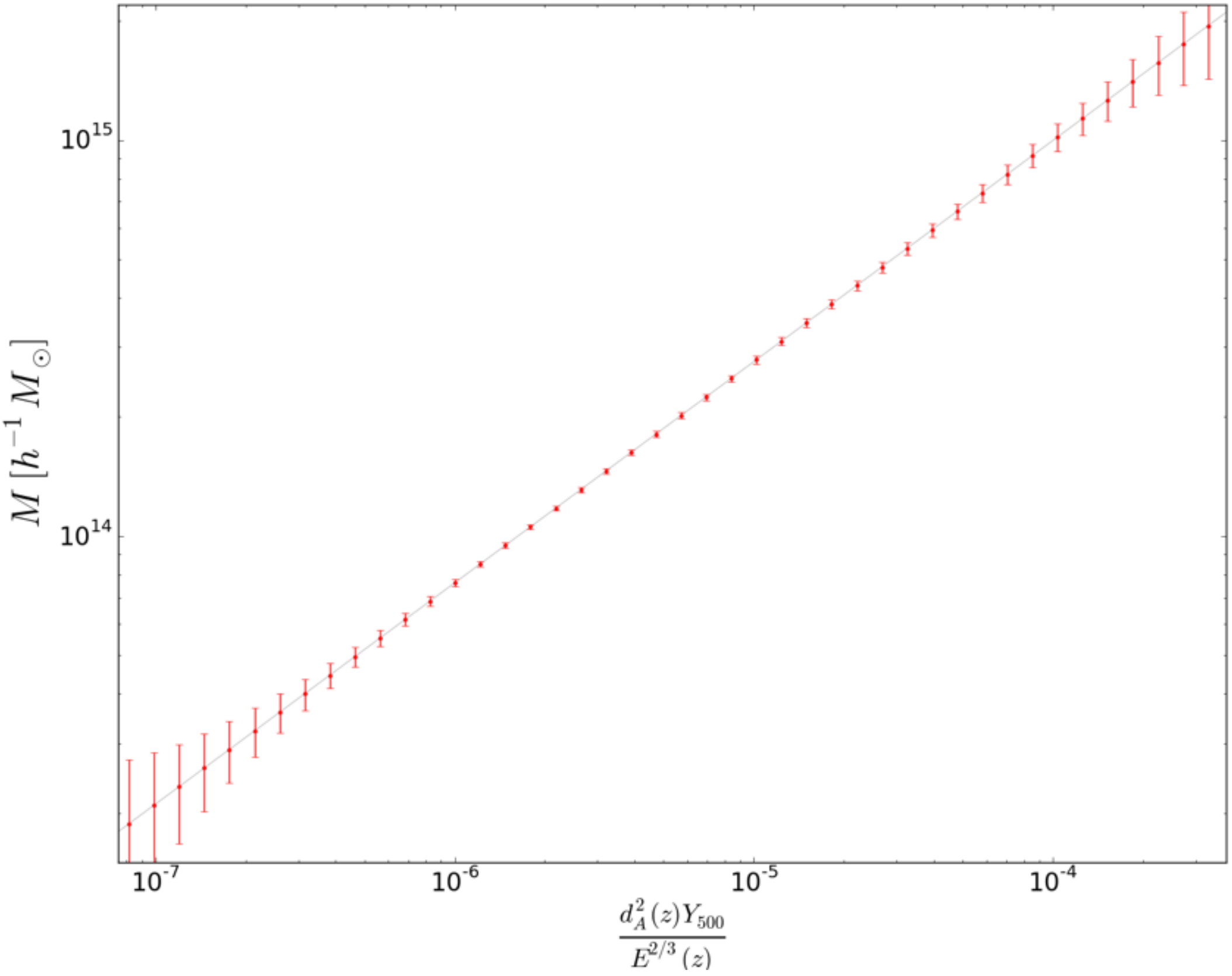
Proposal: can we calibrate the Y-M relationship with CMB data only using gravitational lensing of clusters?

(Melin & Bartlett 2014)

S/N on the cluster distribution

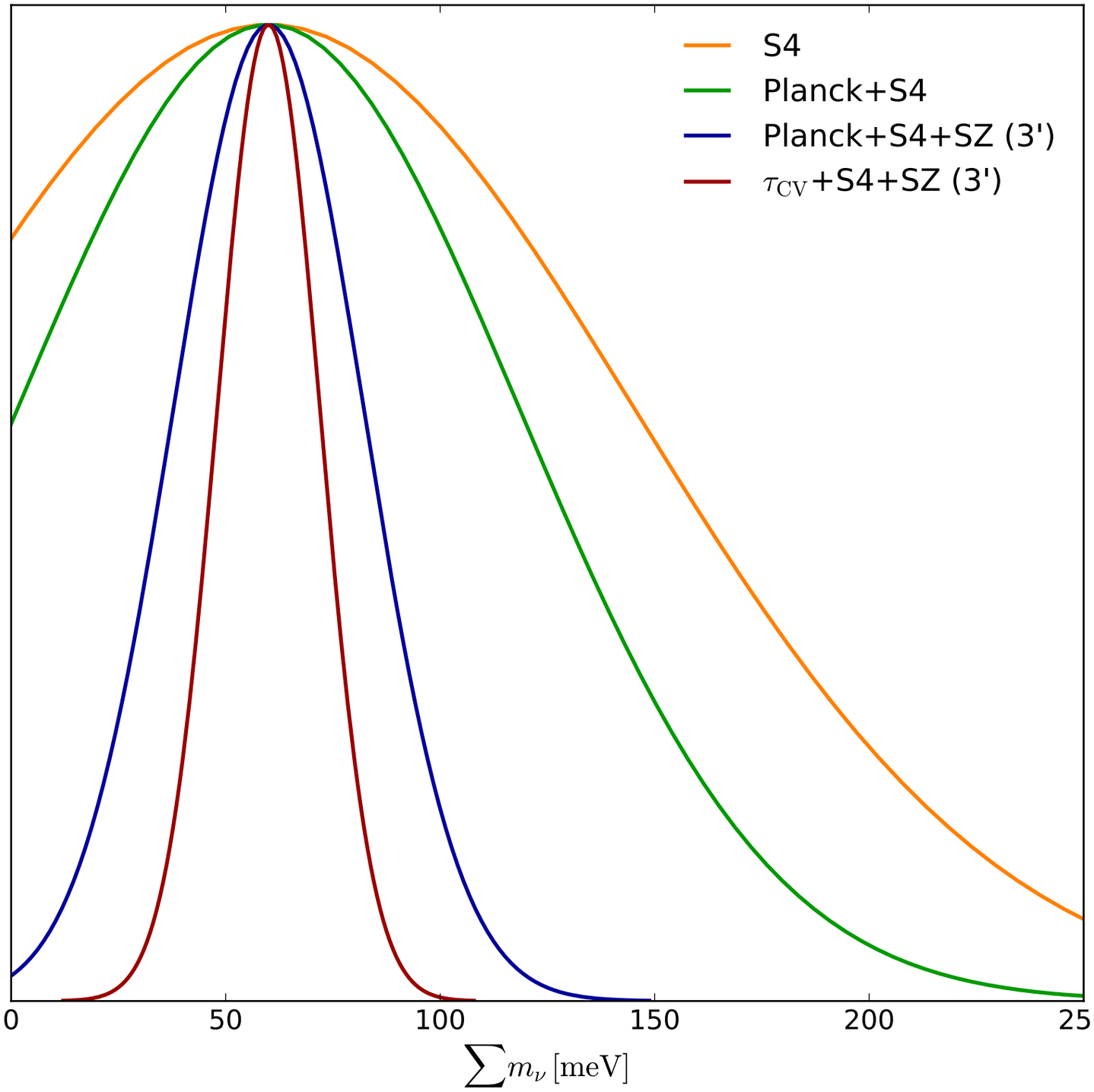


Y-M relationship



Sum of neutrinos masses

5 sigma detection of $\sum m_\nu = 60$ meV from CMB alone !



Louis & Alonso (2016)

Conclusion

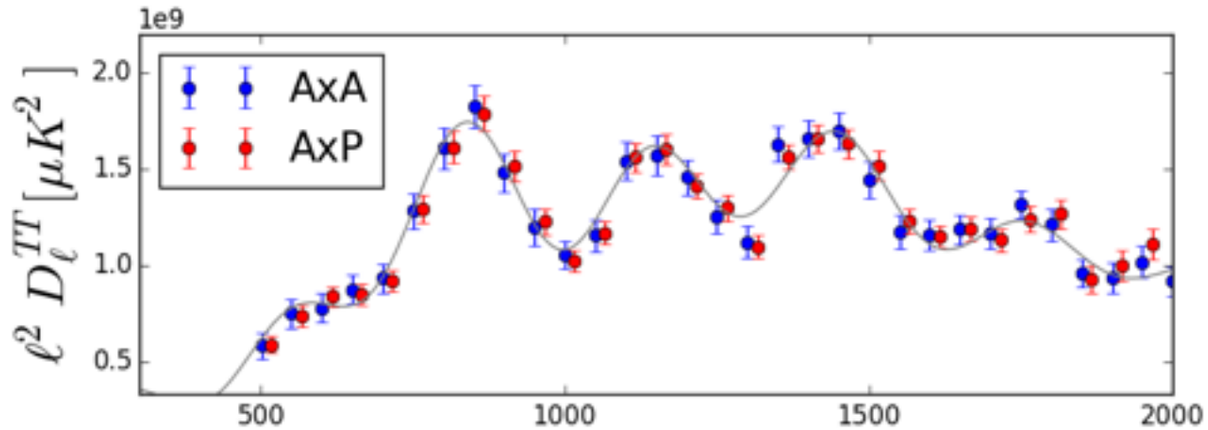
-ACTPol has taken data and allows us to test the LCDM model

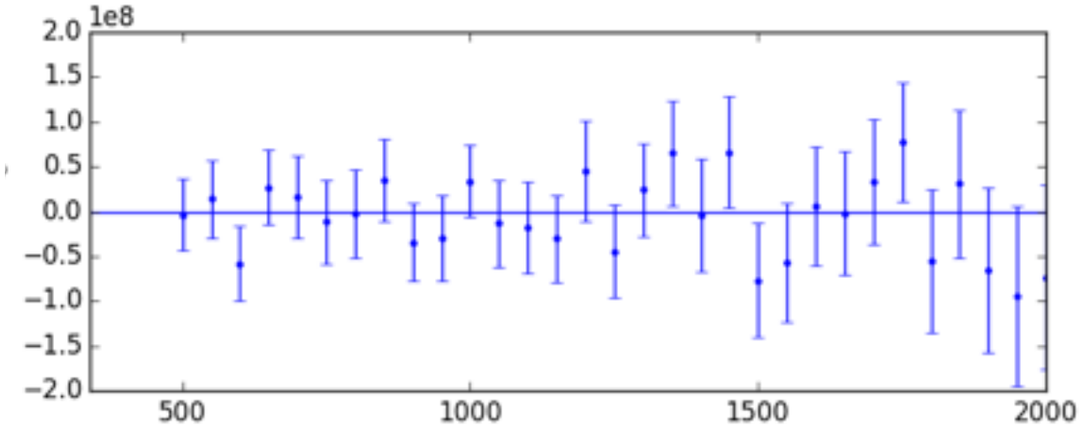
-Planck is over, there are still a lot of modes to map in polarization and lensing

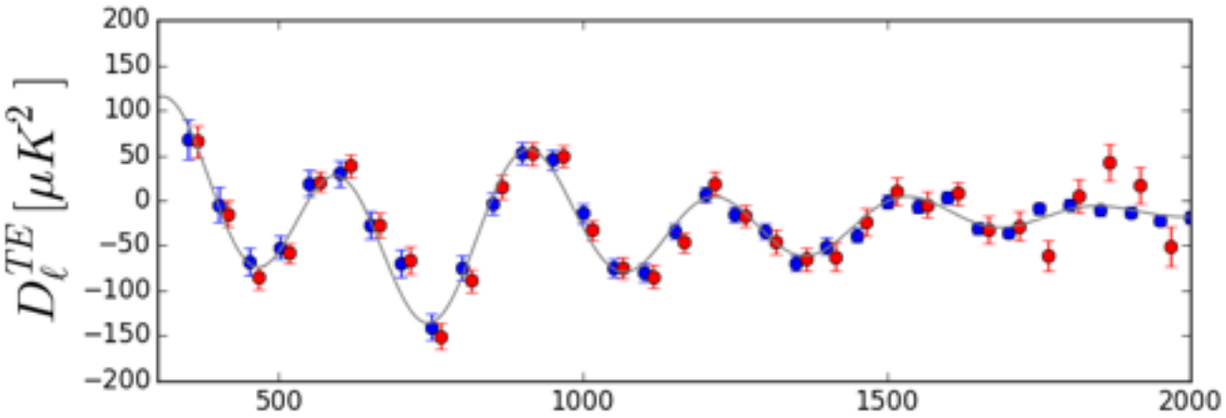
-Advanced ACTPol, Simons Observatory and CMB S4 are on the way

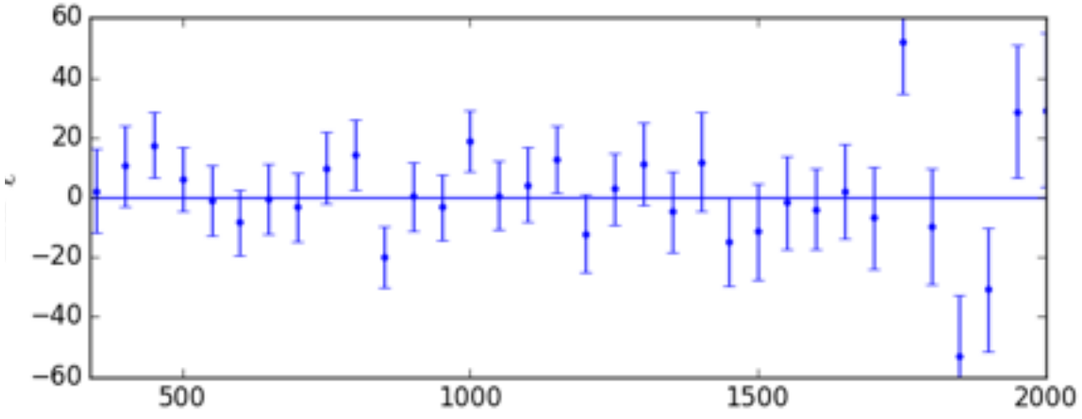
QUBIC and European S4

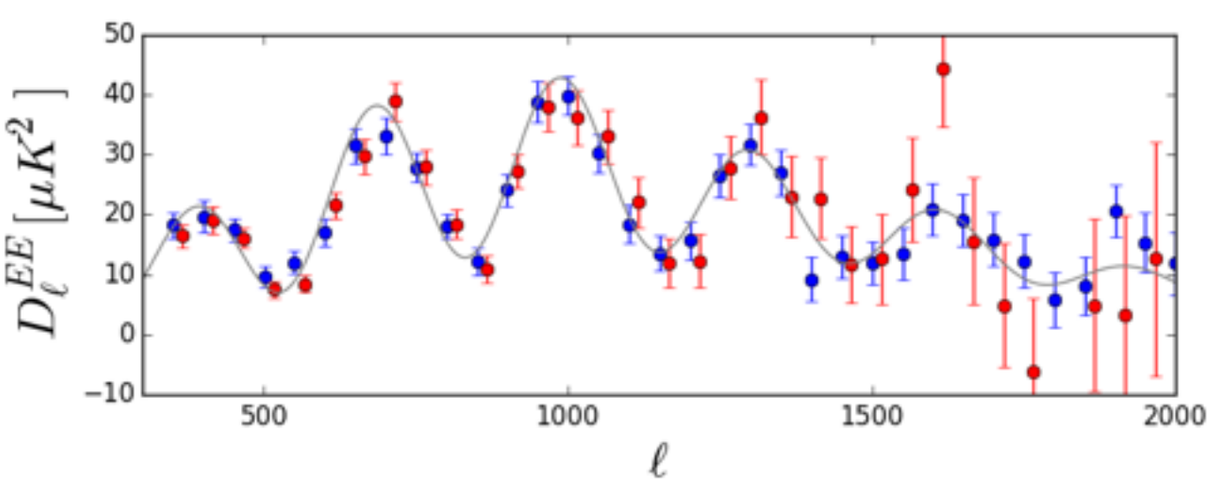
Residuals

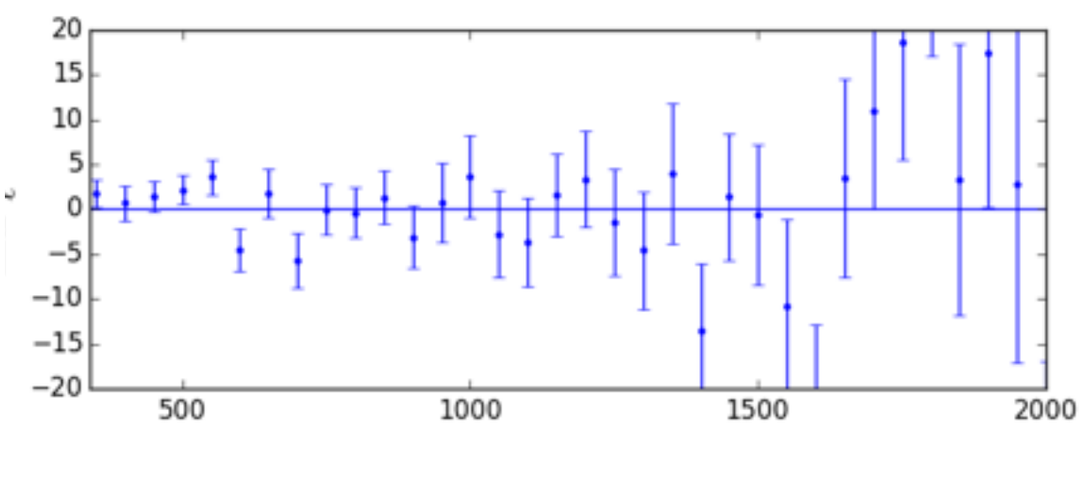

1e9
AxA
AxP
$\ell^2\ D_\ell^{TT}\ [\mu K^2\ ]$
2.0
1.5
1.0
0.5
500
1000
1500
2000

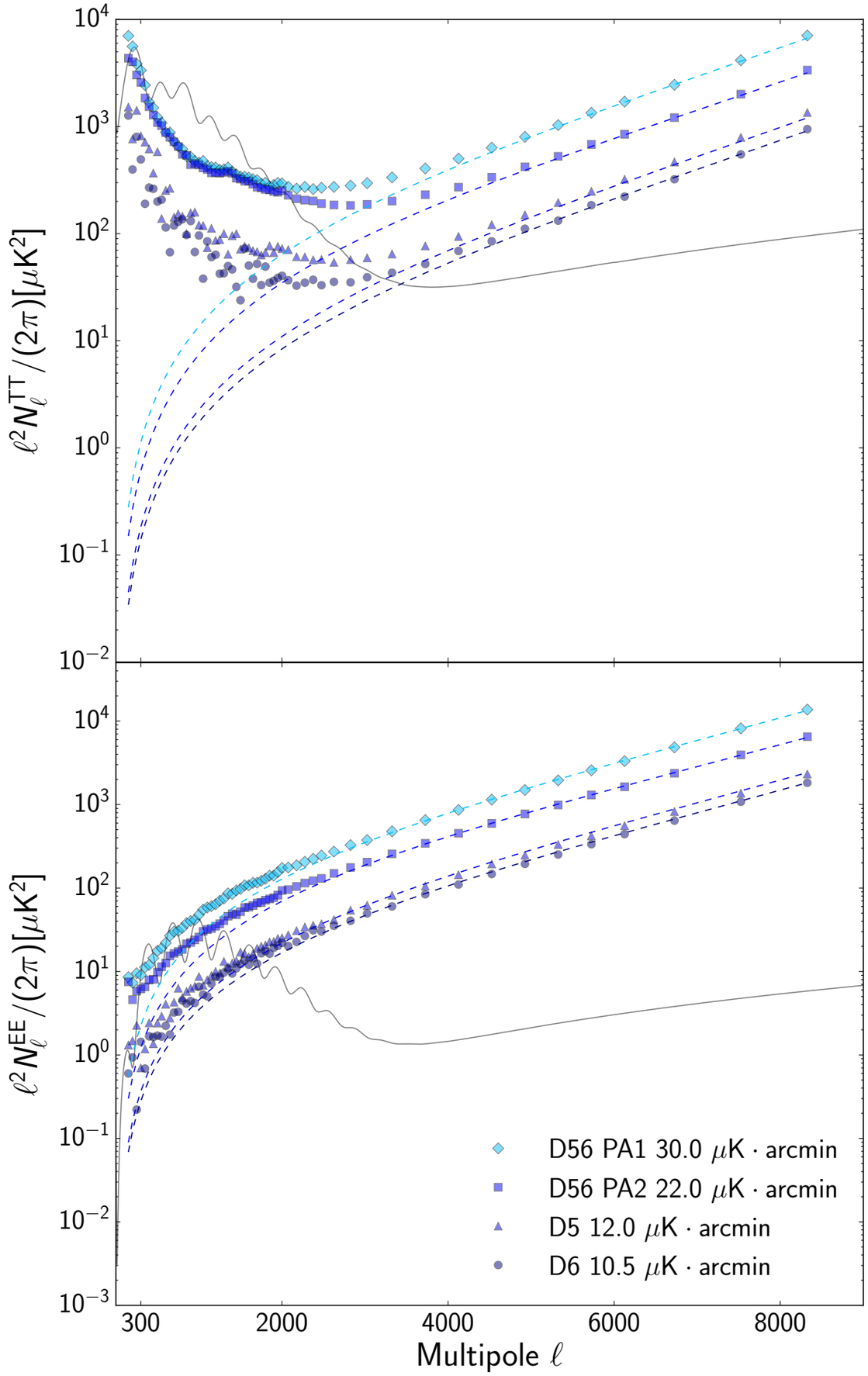

1e8
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
500
1000
1500
2000

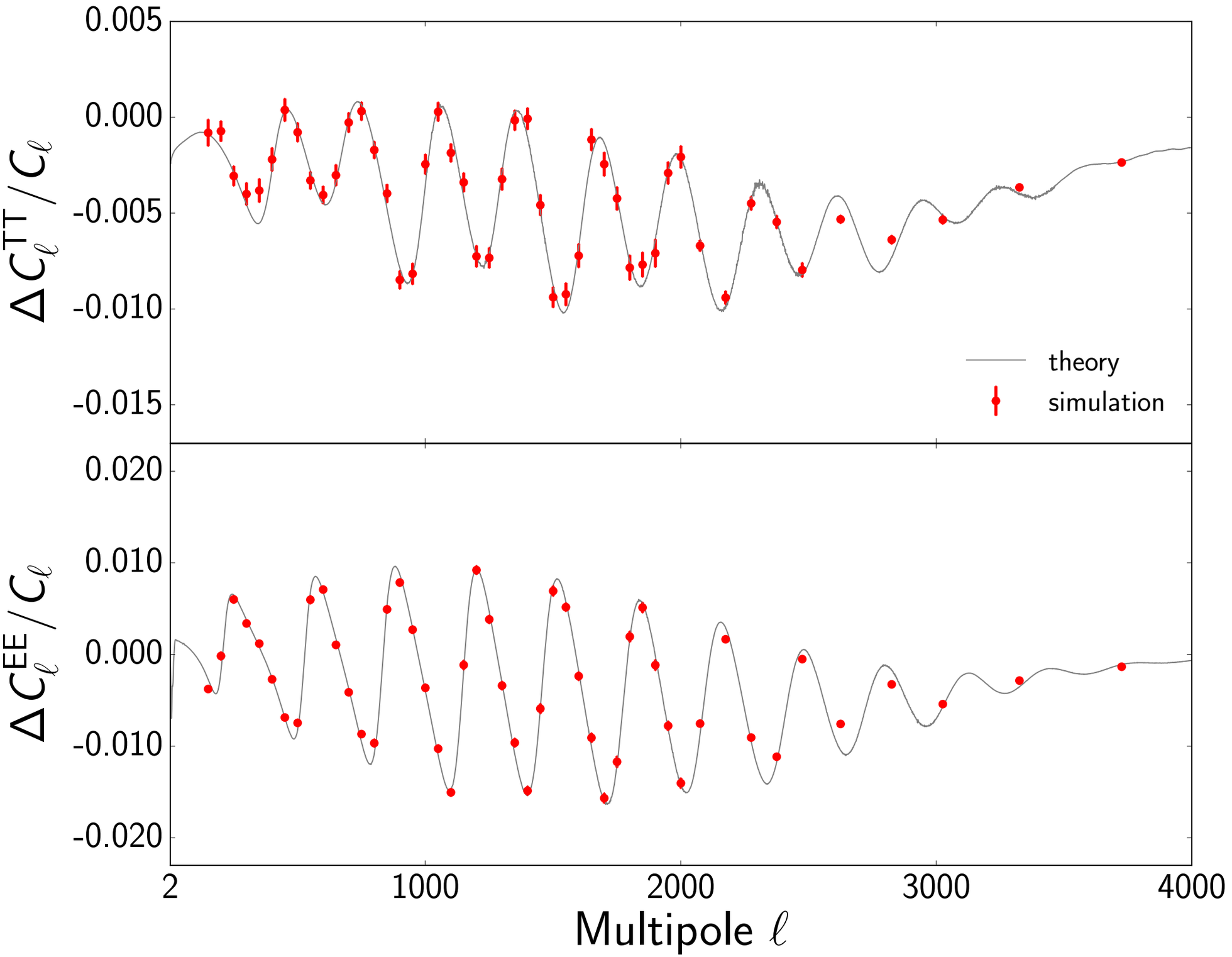

$D_\ell^{TE}\ [\mu K^2\ ]$
200
150
100
50
0
−50
−100
−150
−200
500
1000
1500
2000

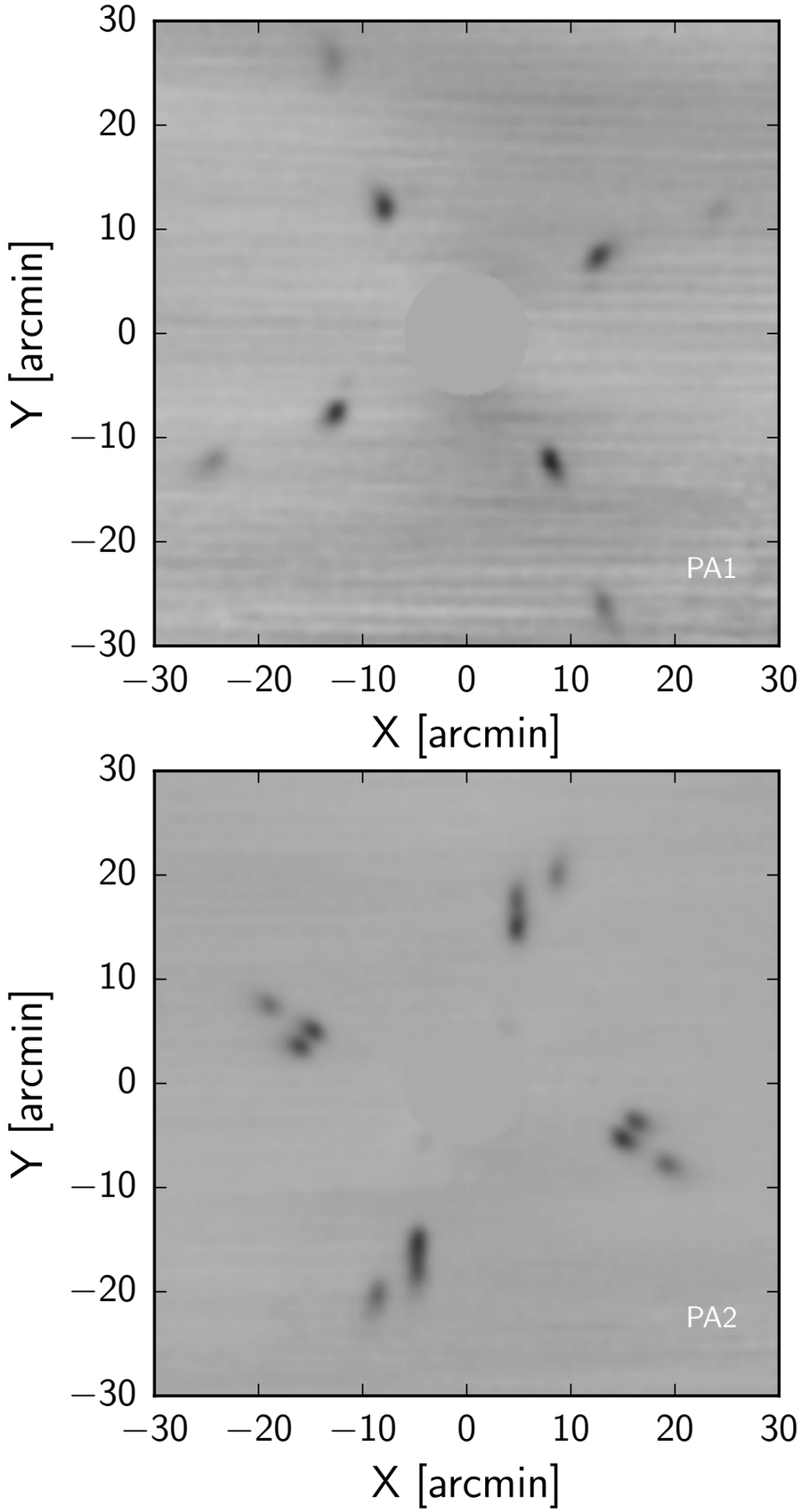

60
40
20
0
−20
−40
−60
500
1000
1500
2000

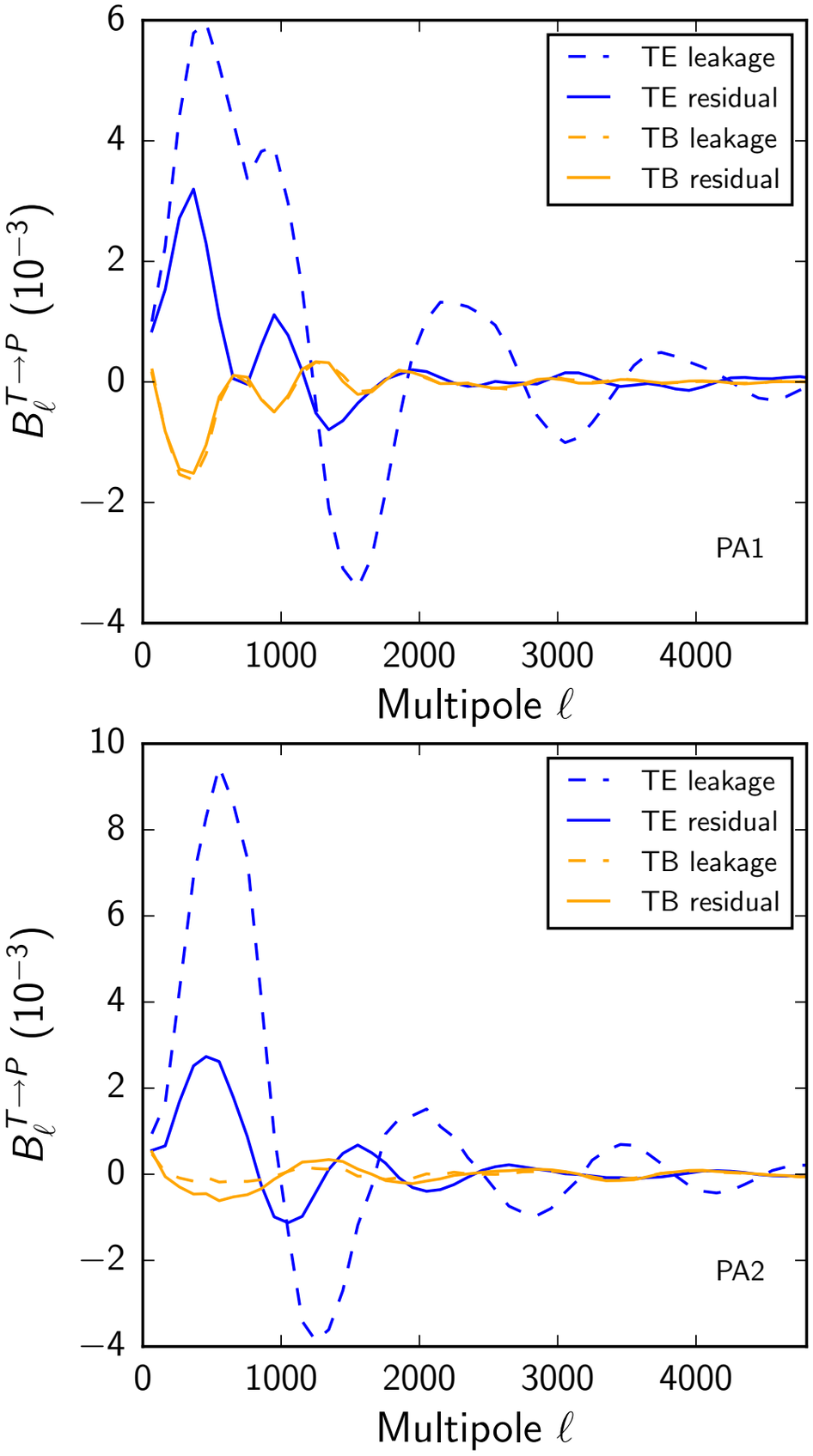

$D_\ell^{EE}\ [\mu K^2\ ]$
50
40
30
20
10
0
−10
500
1000
1500
2000
ℓ


20
15
10
5
0
−5
−10
−15
−20
500
1000
1500
2000


$\ell^2 N_\ell^{\mathrm{TT}}/(2\pi)[\mu\mathrm{K}^2]$
$\ell^2 N_\ell^{\mathrm{EE}}/(2\pi)[\mu\mathrm{K}^2]$
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
300
2000
4000
6000
8000
Multipole ℓ
D56 PA1 30.0 μK · arcmin
D56 PA2 22.0 μK · arcmin
D5 12.0 μK · arcmin
D6 10.5 μK · arcmin


0.005
0.000
-0.005
-0.010
-0.015
$\Delta C_\ell^{\mathrm{TT}} / C_\ell$
theory
simulation
0.020
0.010
0.000
-0.010
-0.020
$\Delta C_\ell^{\mathrm{EE}} / C_\ell$
2
1000
2000
3000
4000
Multipole ℓ


Y [arcmin]
X [arcmin]
PA1
PA2
30
20
10
0
−10
−20
−30


$B_\ell^{T\to P}$ (10^{-3})
Multipole ℓ
TE leakage
TE residual
TB leakage
TB residual
PA1
PA2
6
4
2
0
−2
−4
10
8
0
1000
2000
3000
4000