[AliCPT: 20% Obs efficiency, **S/N~2** in B-map/pix]

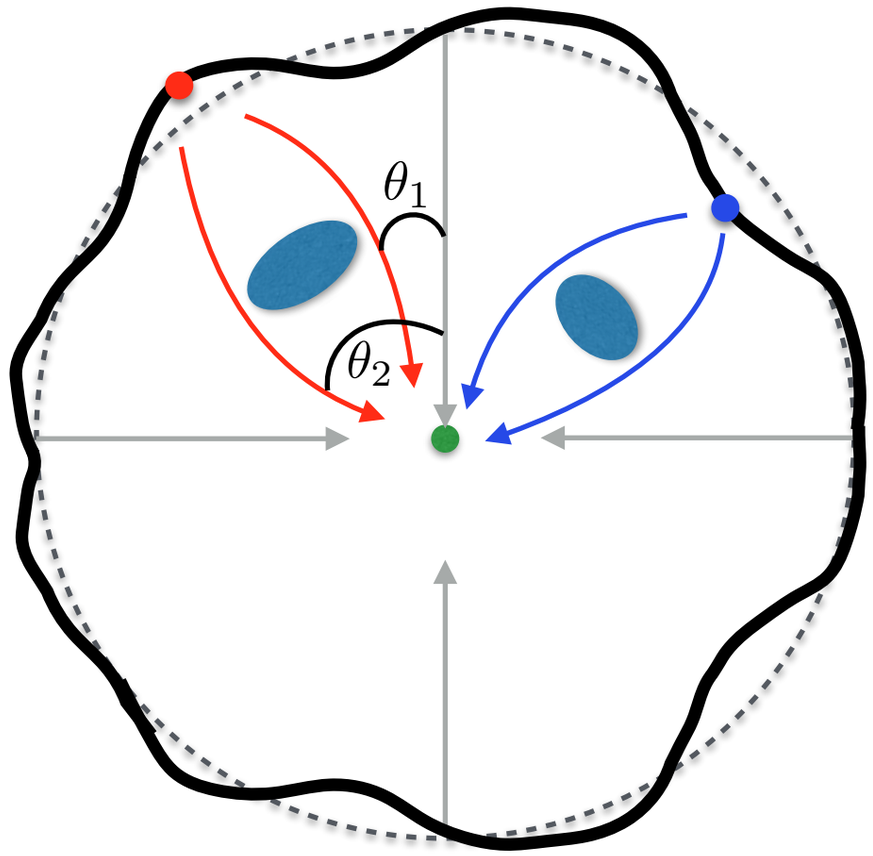
CMB Lensing

Bin Hu @ BNU

Lensing: mixing different ells

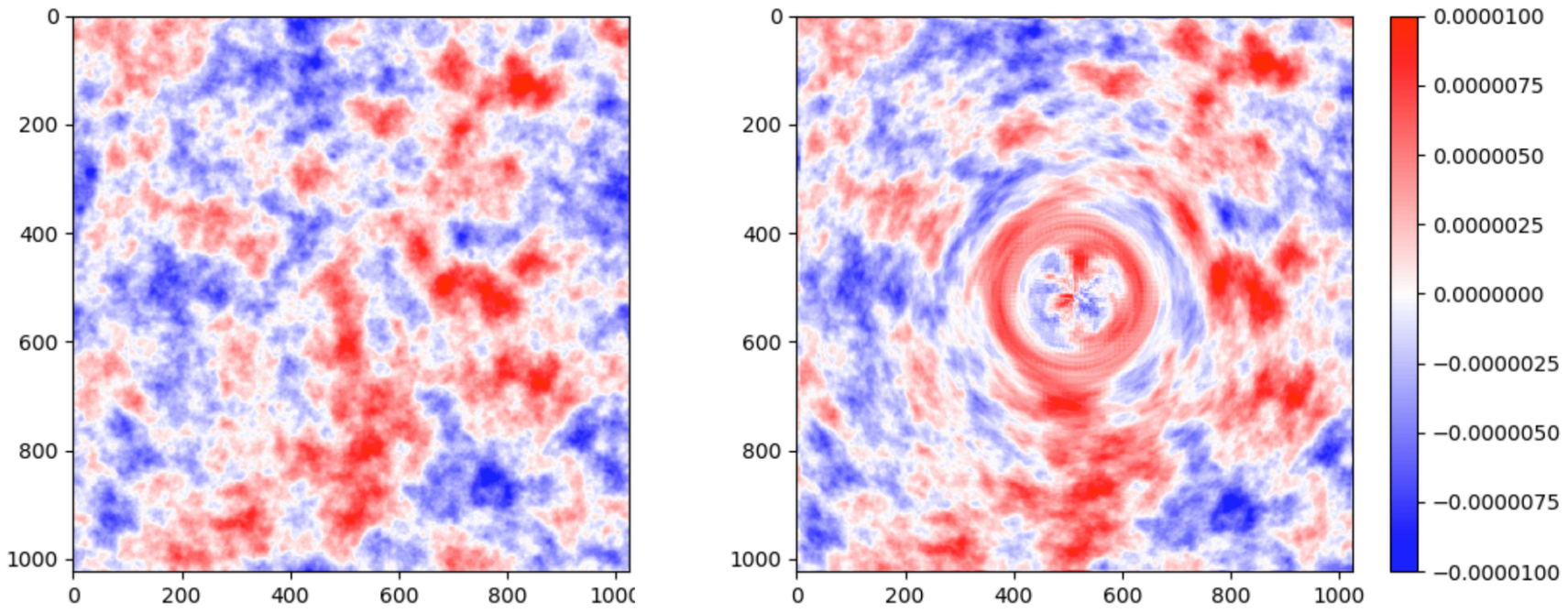
conservation of surface brightness

$$\tilde{\Theta}(\mathbf{x}) = \Theta(\mathbf{x}') = \Theta(\mathbf{x} + \boldsymbol{\nabla}\psi)$$



mixing different ells

$$\tilde{\Theta}(\mathbf{l}) \approx \Theta(\mathbf{l}) - \int \frac{\mathrm{d}^2\mathbf{l}'}{2\pi}\, \mathbf{l}' \cdot (\mathbf{l} - \mathbf{l}')\psi(\mathbf{l} - \mathbf{l}')\Theta(\mathbf{l}')$$



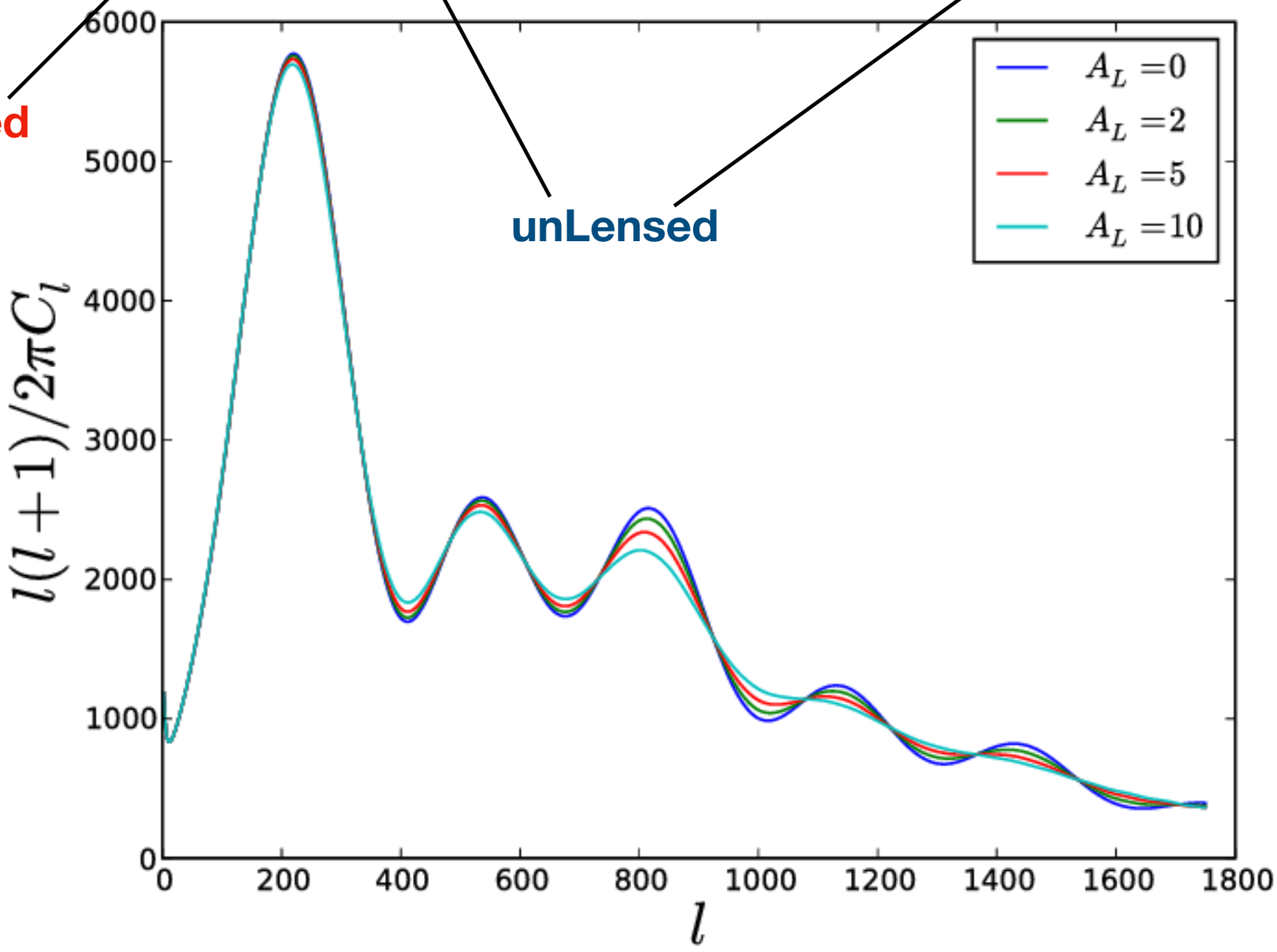
[Zhengyi WANG]

Lensing: smearing acoustic peak

$$\tilde{\Theta}(\mathbf{l}) \approx \Theta(\mathbf{l}) - \int \frac{\mathrm{d}^2\mathbf{l}'}{2\pi}\, \mathbf{l}' \cdot (\mathbf{l}-\mathbf{l}')\psi(\mathbf{l}-\mathbf{l}')\Theta(\mathbf{l}')$$

Lensed

unLensed



Reconstruction

$$\tilde{\Theta}(\mathbf{l}) \approx \Theta(\mathbf{l}) - \int \frac{\mathrm{d}^2\mathbf{l}'}{2\pi}\, \mathbf{l}' \cdot (\mathbf{l}-\mathbf{l}')\psi(\mathbf{l}-\mathbf{l}')\Theta(\mathbf{l}')$$

Core-1: Reverse a non-linear process!

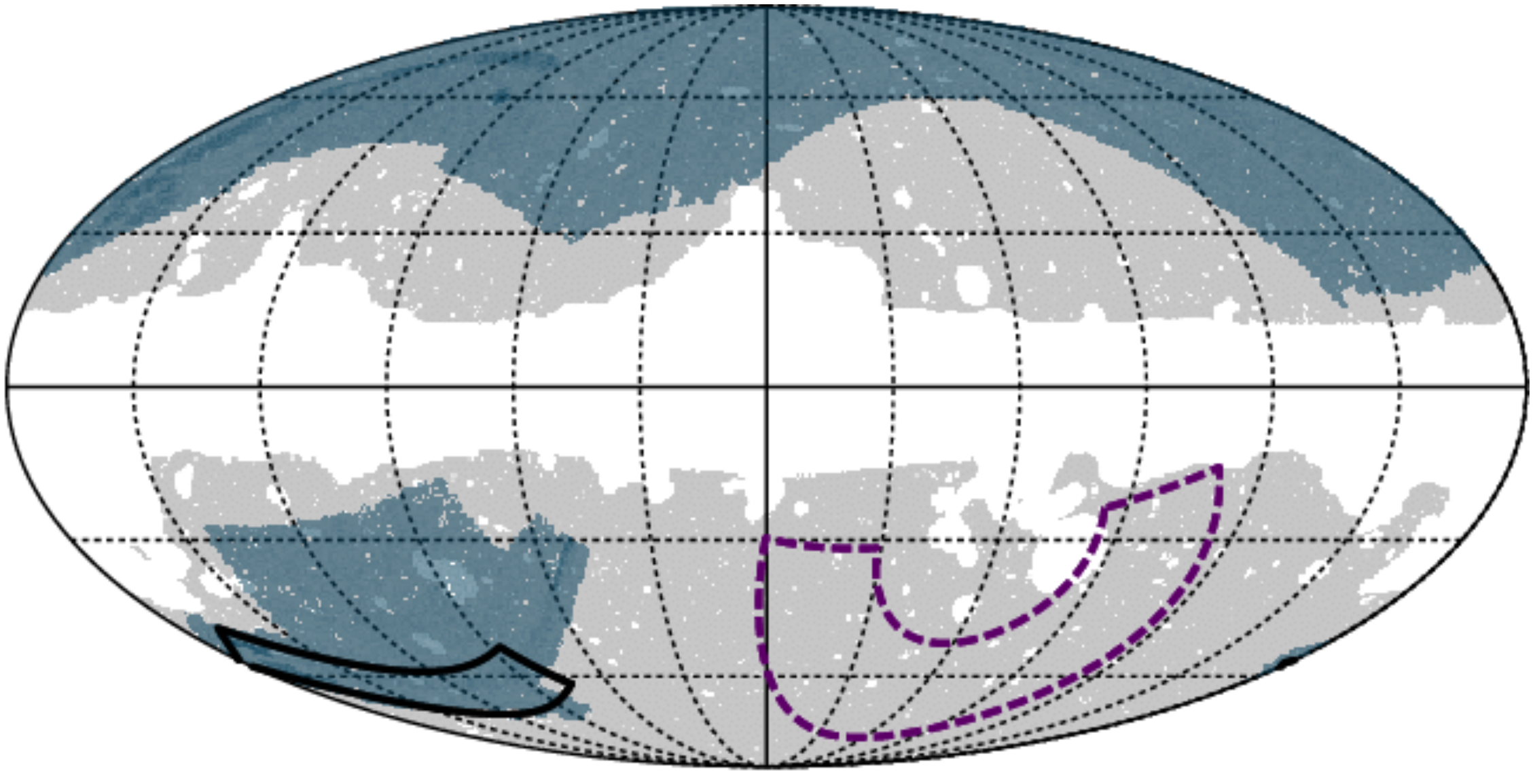
External help

cross-correlate with galaxy catalog

gray: Planck CMB map

galaxy trace gravitational potential (roughly)

blue: SDSS-DR8



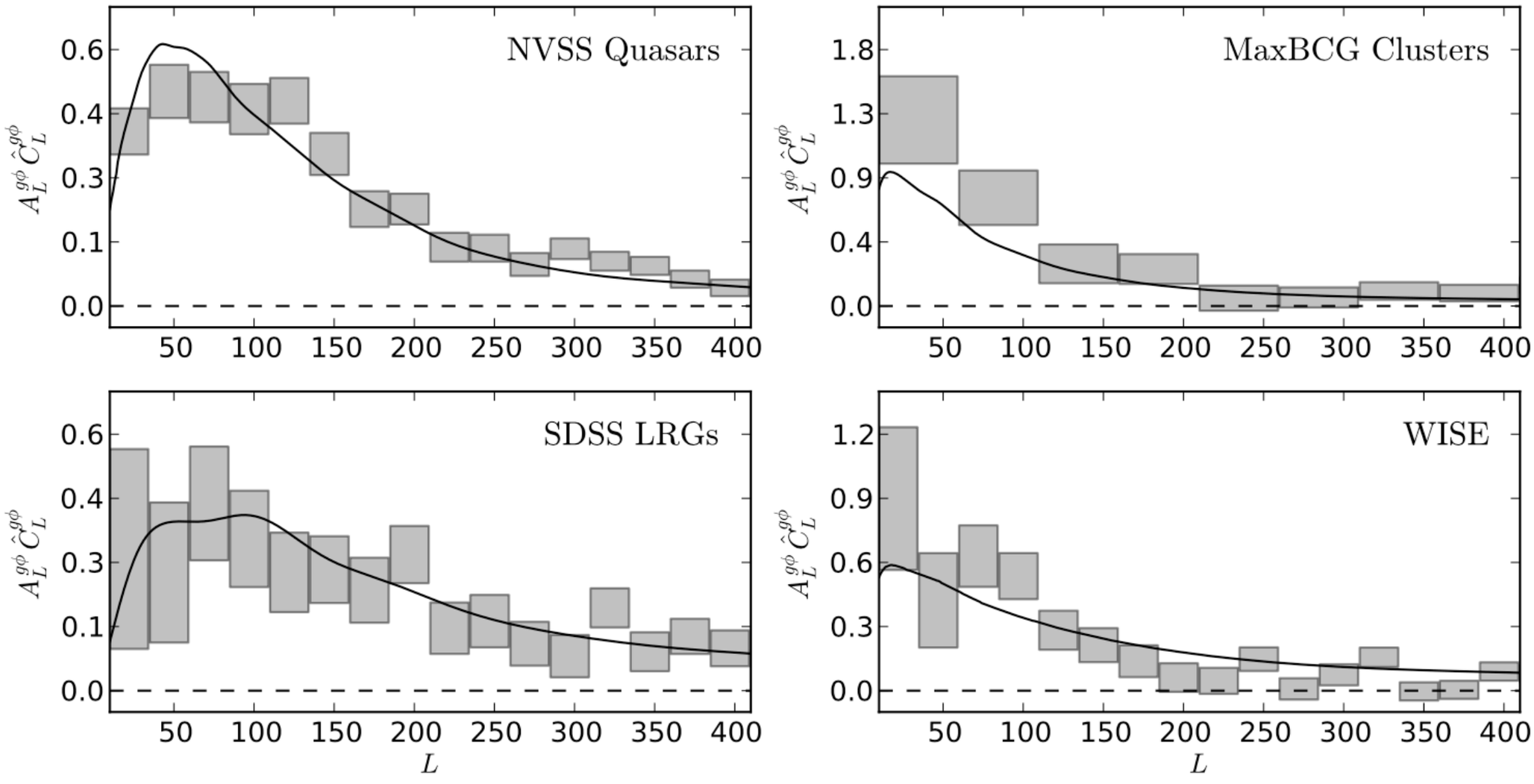
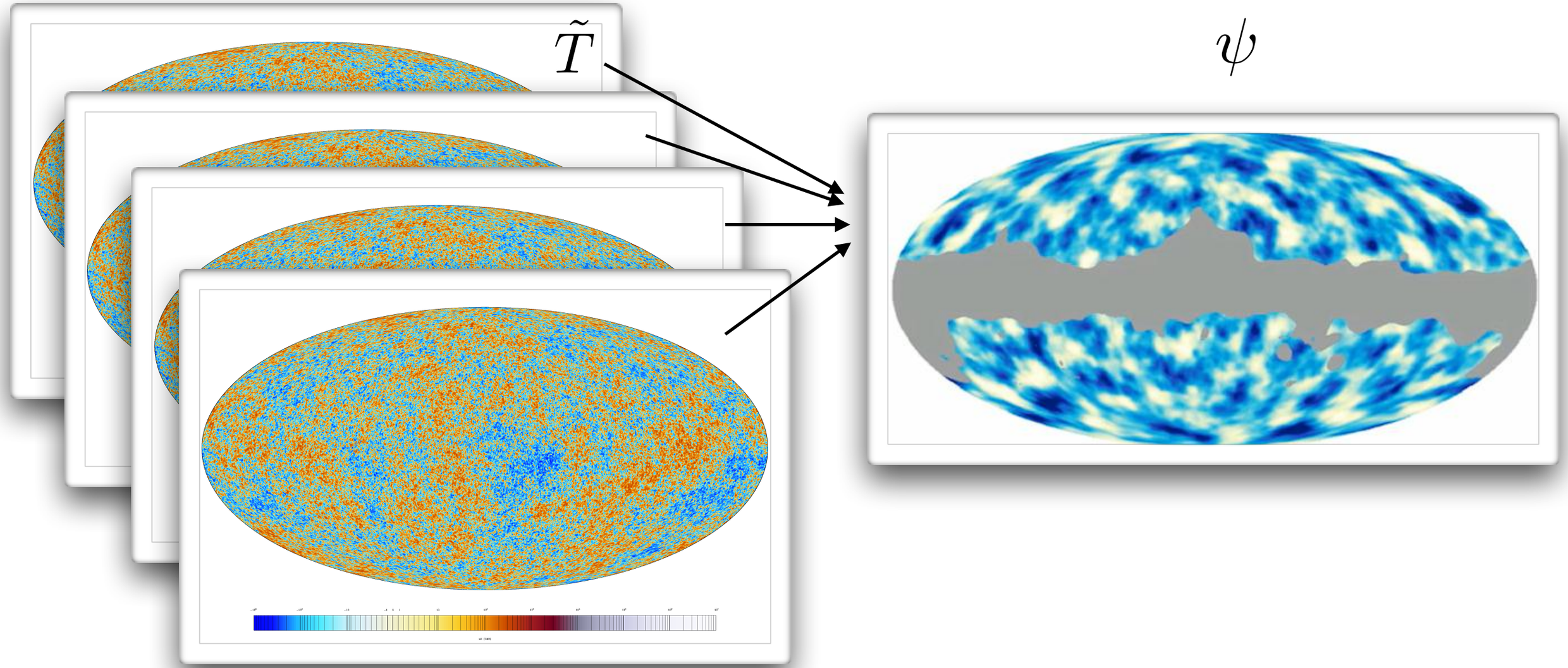
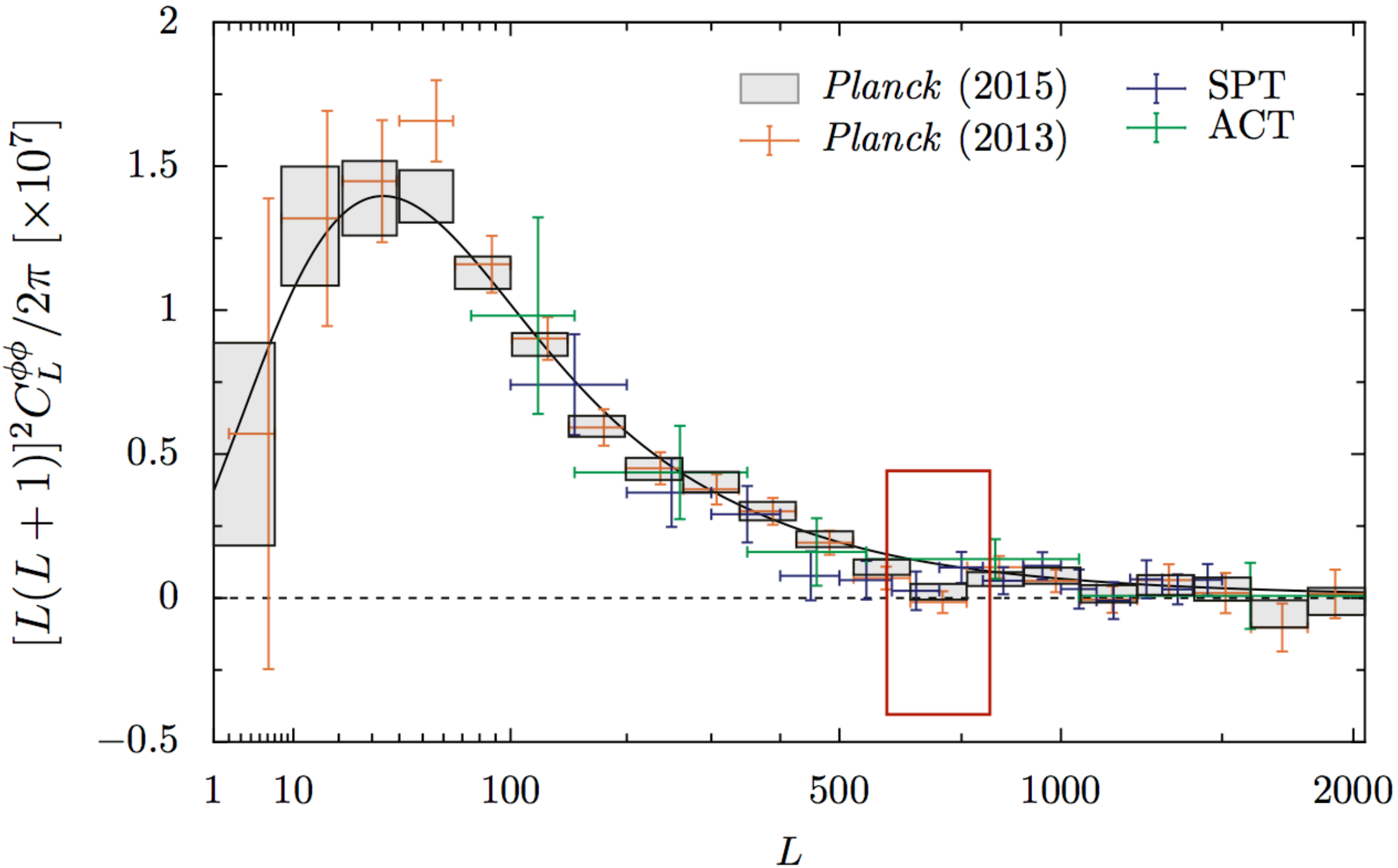


Fig. 17. Cross-spectra of the *Planck* MV lensing potential with several galaxy catalogs, scaled by the signal-to-noise weighting factor $A_L^{g\phi}$ defined in Eq. (52). Cross-correlations are detected at approximately 20σ significance for the NVSS quasar catalog, 10σ for SDSS LRGs, and 7σ for both MaxBCG and WISE.

$$\sim 10\sigma$$

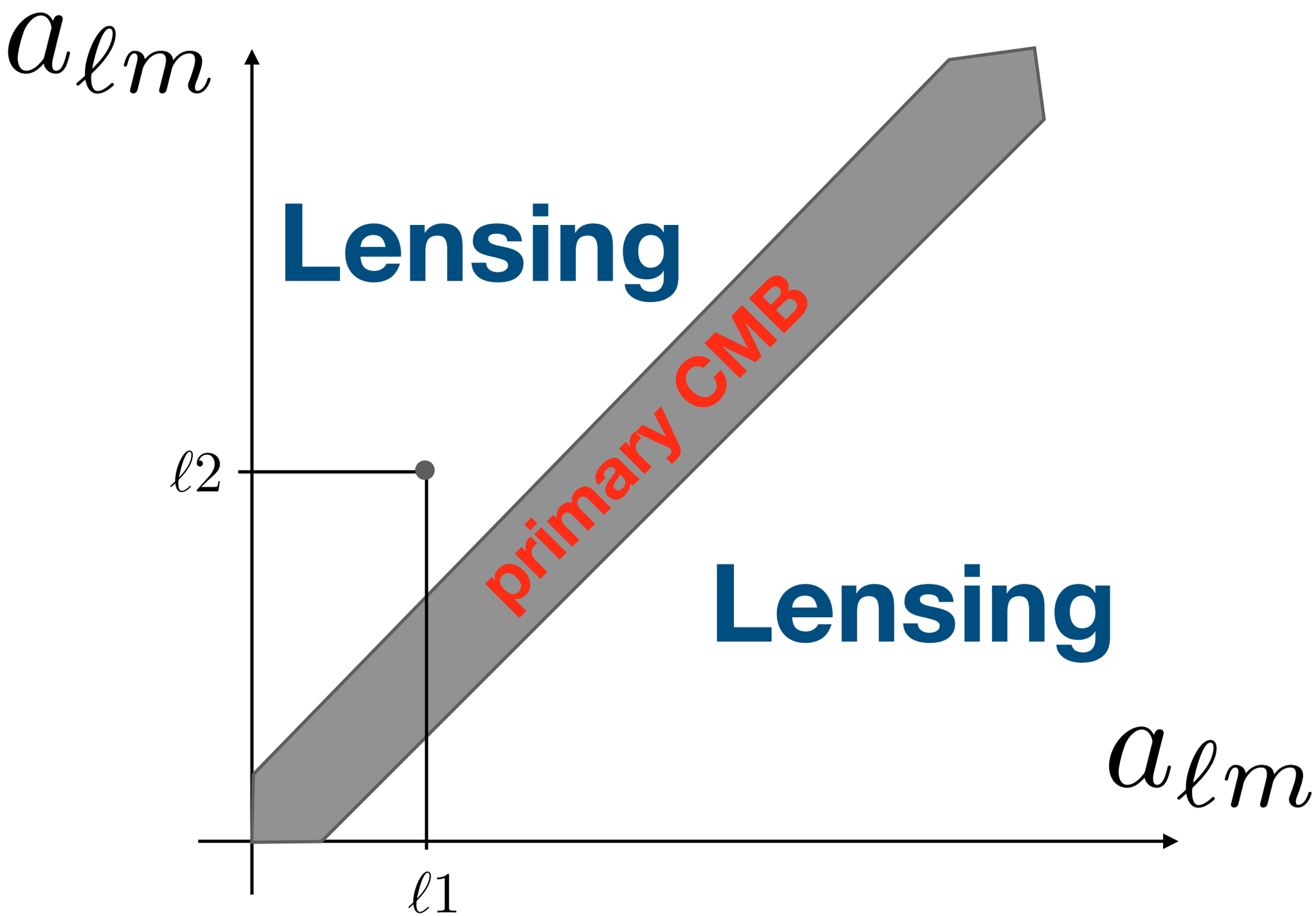
Can we do it Internally ?




Planck (2015)
Planck (2013)
SPT
ACT
$[L(L+1)]^2 C_L^{\phi\phi}/2\pi\ [\times 10^7]$
2
1.5
1
0.5
0
−0.5
1
10
100
500
1000
2000
L

40σ

Higher order statistics



Quadratic estimator

Hu-Okamoto 08’

Give optimal weight to different ell, and minimize the errors

$$\hat{\phi}_{LM} \sim \frac{\bar{x}_{LM}}{R_L}$$

Trispectrum (4pt)

Normalization factor

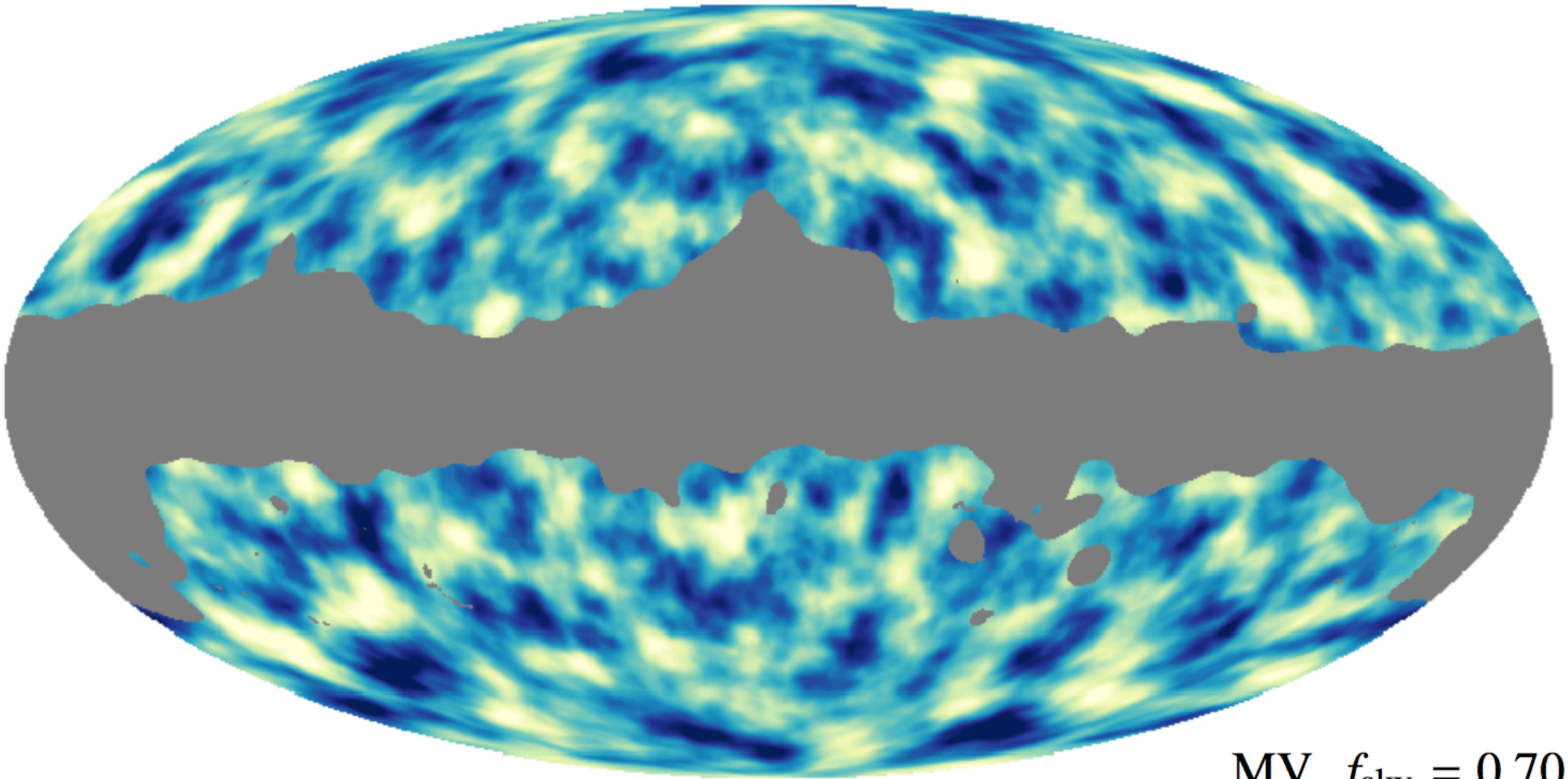
$$\bar{x}_{LM} \sim W_{\ell_1 \ell_2 L} \bar{T}_{\ell_1 m_1} \bar{T}_{\ell_2 m_2}$$

$$R_L \sim W^2_{\ell_1 \ell_2 L}$$

Window Func

$$\hat{\phi}_{LM} \sim \frac{(\bar{T}\bar{T})(\bar{T}\bar{T}\phi)}{(\bar{T}\bar{T})^2} \sim \phi$$

However, $\hat{\phi}_{LM}$ is very very noisy!



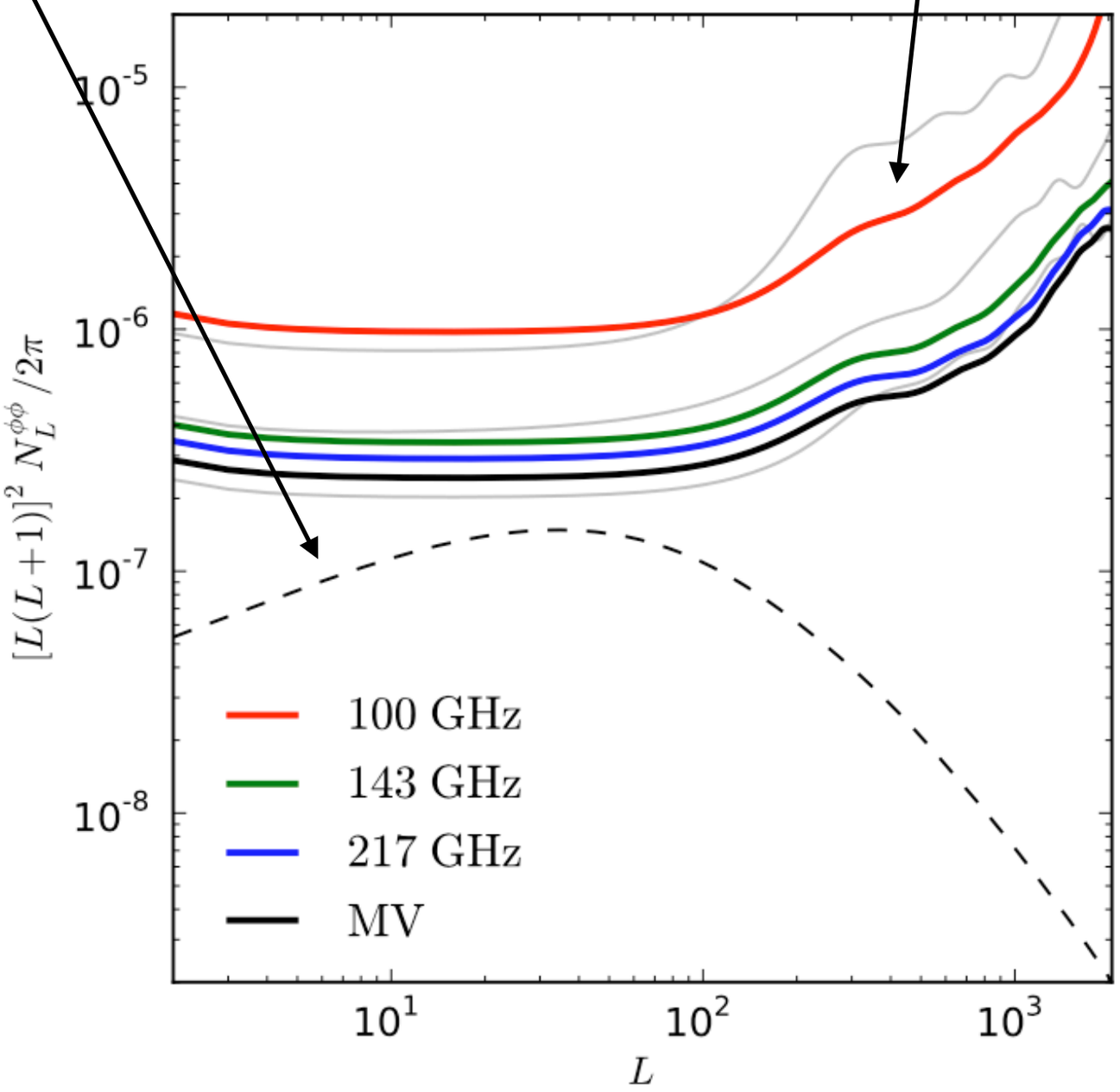
MV, $f_{\rm sky} = 0.70$

signal

estimator

unavoidable noise (from primary cmb)

$$\hat{C}_L^{\phi\phi} = \frac{1}{(2L+1)f_{sky}} \sum_M |\hat{\phi}_{LM}|^2 - \Delta C_L^{\phi\phi}|_{N_0} + \cdots$$



[Planck 2013]

Noise level estimation for AliCPT

- Using **flat-sky** approximation
  - `AliCPT FWHM of the beam [arcmin] #fwmh_arcmin = 12.0`
  - `AliCPT noise [\mu K*arcmin]`

```
D_T_arcmin = 9.0  D_P_arcmin = 9.0*np.sqrt(2)
```

CAN be better!

Probing Primordial Gravitational Waves: Ali CMB Polarization Telescope*

Hong Li[1], Si-Yu Li[1], Yang Liu[2,3], Yong-Ping Li[2,3], Yifu Cai[4], Mingzhe Li[5], Gong-Bo Zhao[6,7], Cong-Zhan Liu[1], Zheng-Wei Li[1], He Xu[1], Di Wu[1], Yong-Jie Zhang[1], Zu-Hui Fan[8], Yong-Qiang Yao[6], Chao-Lin Kuo [9], Fang-Jun Lu[1] and Xinmin Zhang[2,3]

[1] *Key Laboratory of Particle Astrophysics, Institute of High Energy Physics (IHEP), Chinese Academy of Sciences, 19B Yuquan Road, Shijingshan District, Beijing 100049, China*

[2] *Theoretical Physics Division, Institute of High Energy Physics (IHEP), Chinese Academy of Sciences, 19B Yuquan Road, Shijingshan District, Beijing 100049, China*

[3] *University of Chinese Academy of Sciences, Beijing, China*

[4] *CAS Key Laboratory for Researches in Galaxies and Cosmology, Department of Astronomy, University of Science and Technology of China, Hefei, Anhui 230026, China*

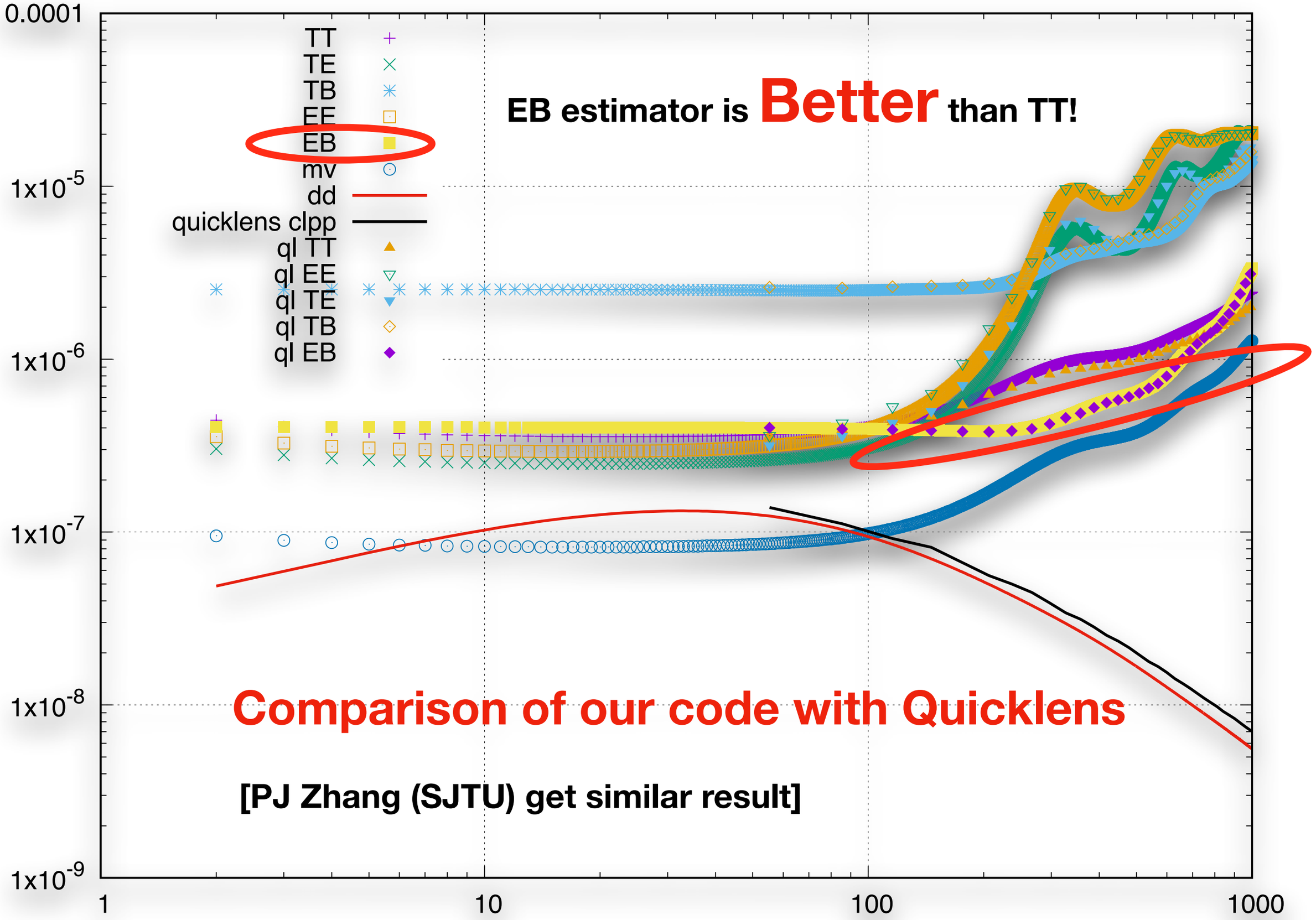
[5] *Interdisciplinary Center for Theoretical Study, University of Science and Technology of China, Hefei, Anhui 230026, China*

[6] *National Astronomical Observatories, Chinese Academy of Science, Jia 20, Datun Road, Chaoyang District, Beijing 100012, P.R.China*

[7] *Institute of Cosmology & Gravitation, University of Portsmouth, Dennis Sciama Building, Portsmouth, PO1 3FX, UK*

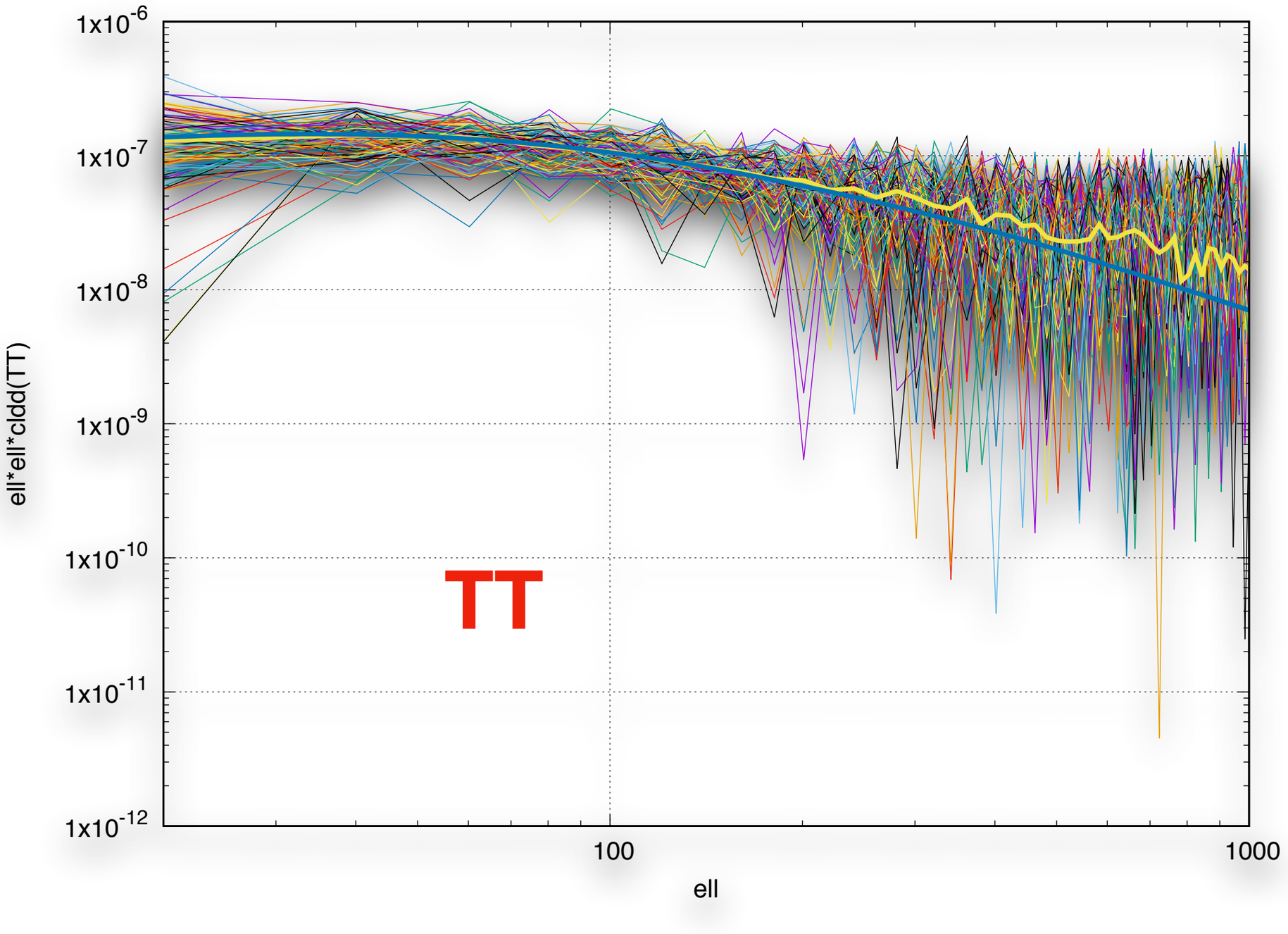
[8] *Department of Astronomy, School of Physics, Peking University, Beijing 100871, China and*

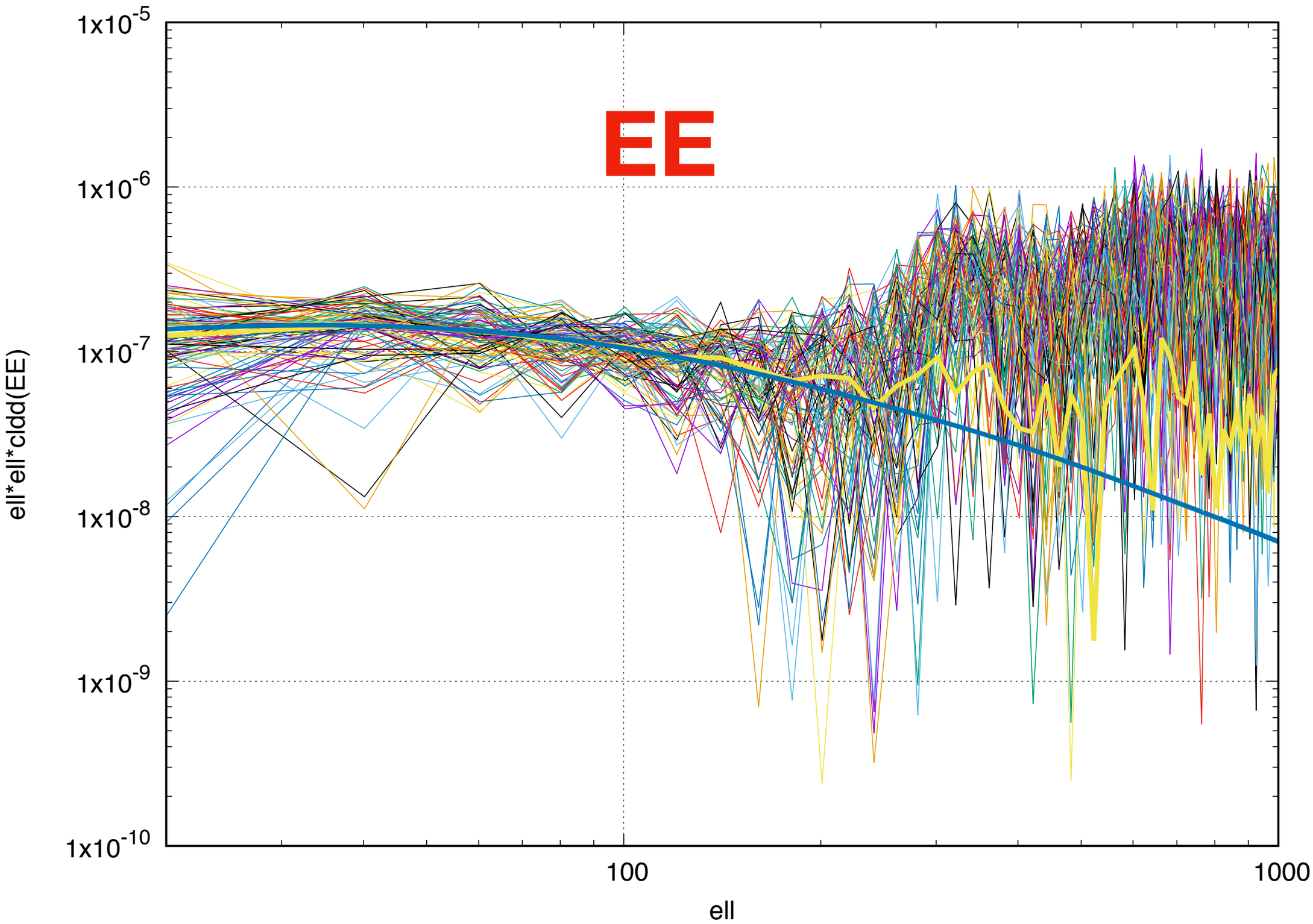
Feb 2018

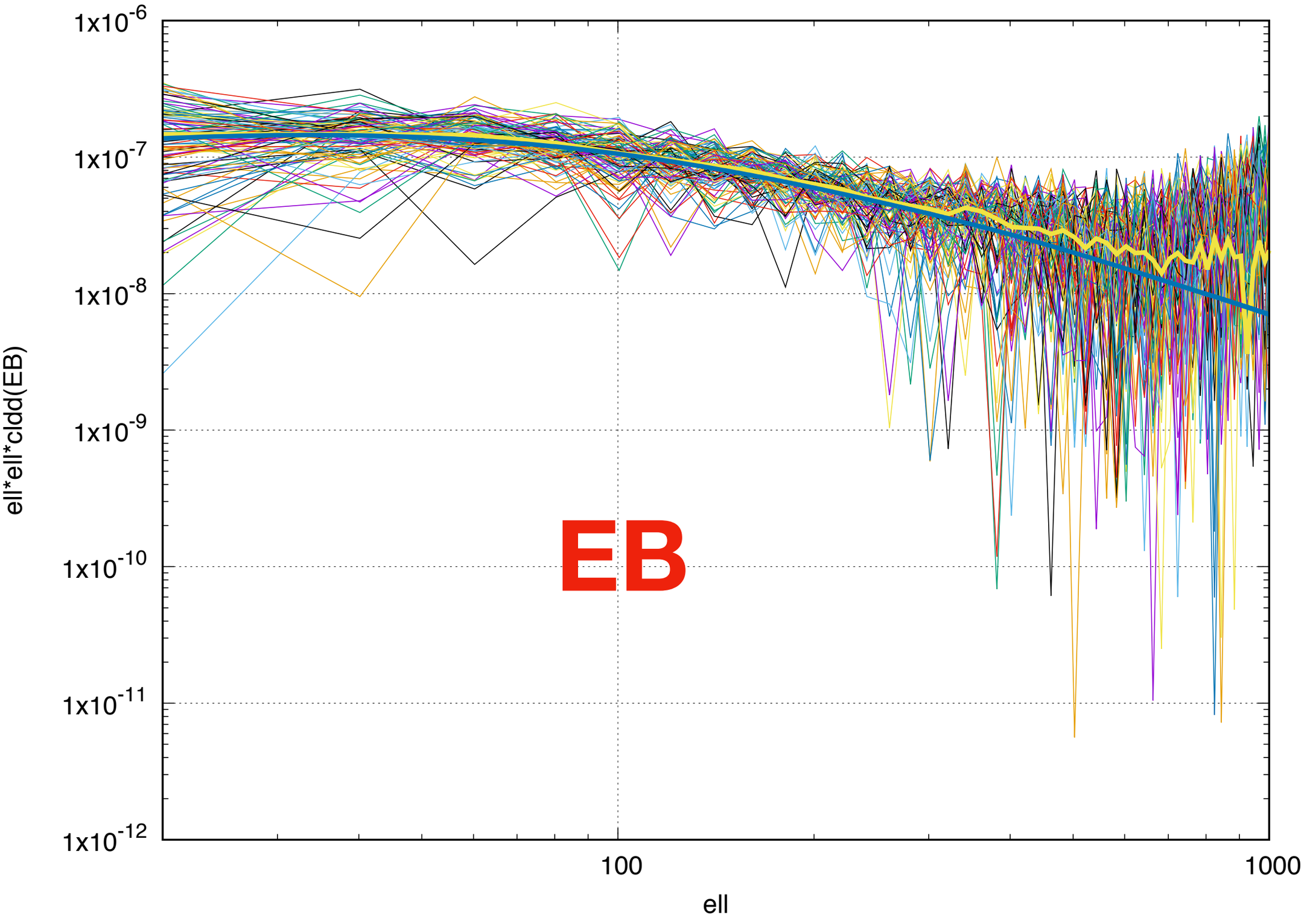

0.0001
1x10-5
1x10-6
1x10-7
1x10-8
1x10-9
1
10
100
1000
TT
TE
TB
EE
EB
mv
dd
quicklens clpp
ql TT
ql EE
ql TE
ql TB
ql EB
EB estimator is Better than TT!
Comparison of our code with Quicklens
[PJ Zhang (SJTU) get similar result]

Simulation for 4000 degsq

quicklens (Planck pipeline) by Duncan Hanson

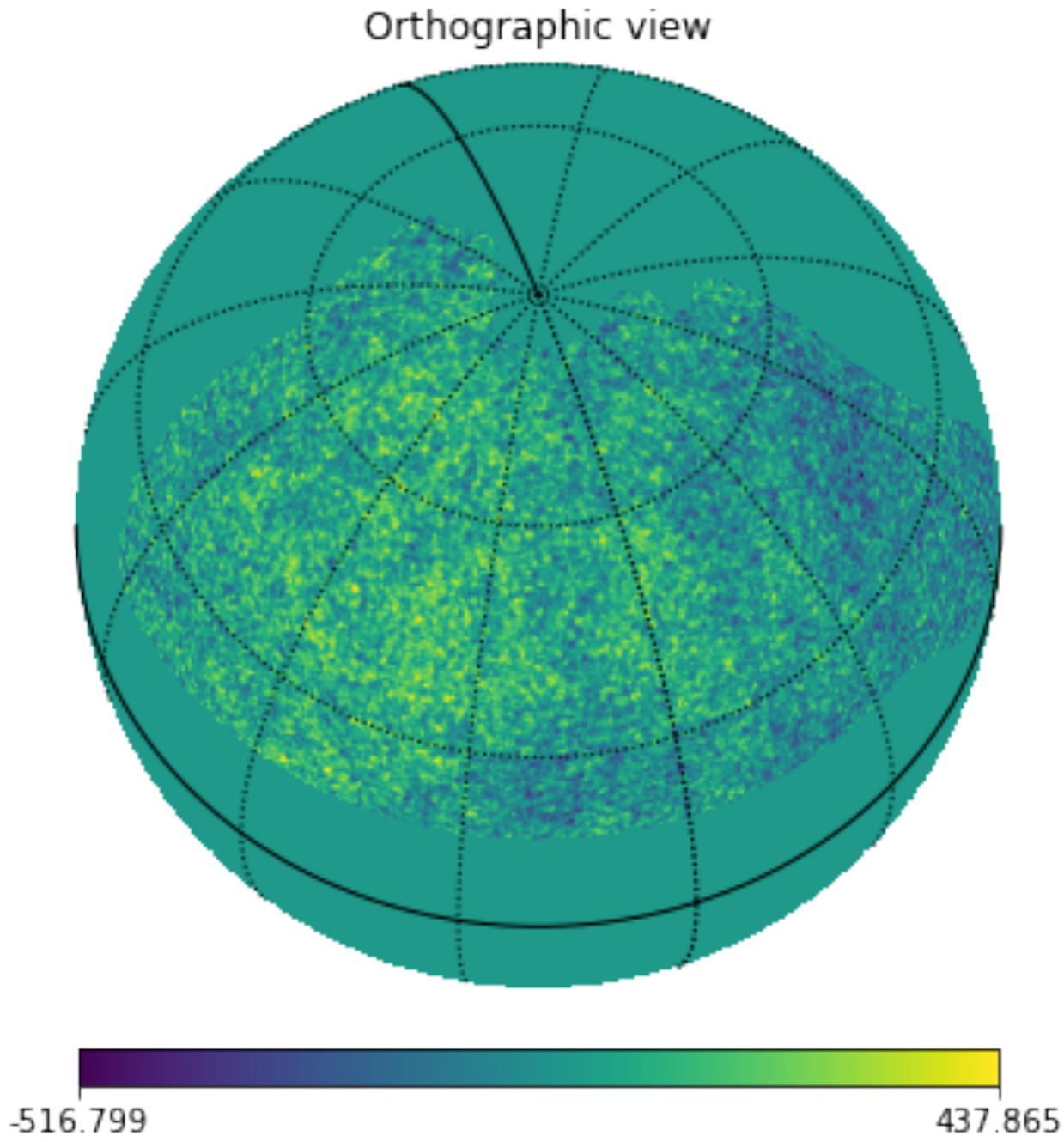



EE
1x10-5
1x10-6
1x10-7
1x10-8
1x10-9
1x10-10
ell*ell*cldd(EE)
100
1000
ell

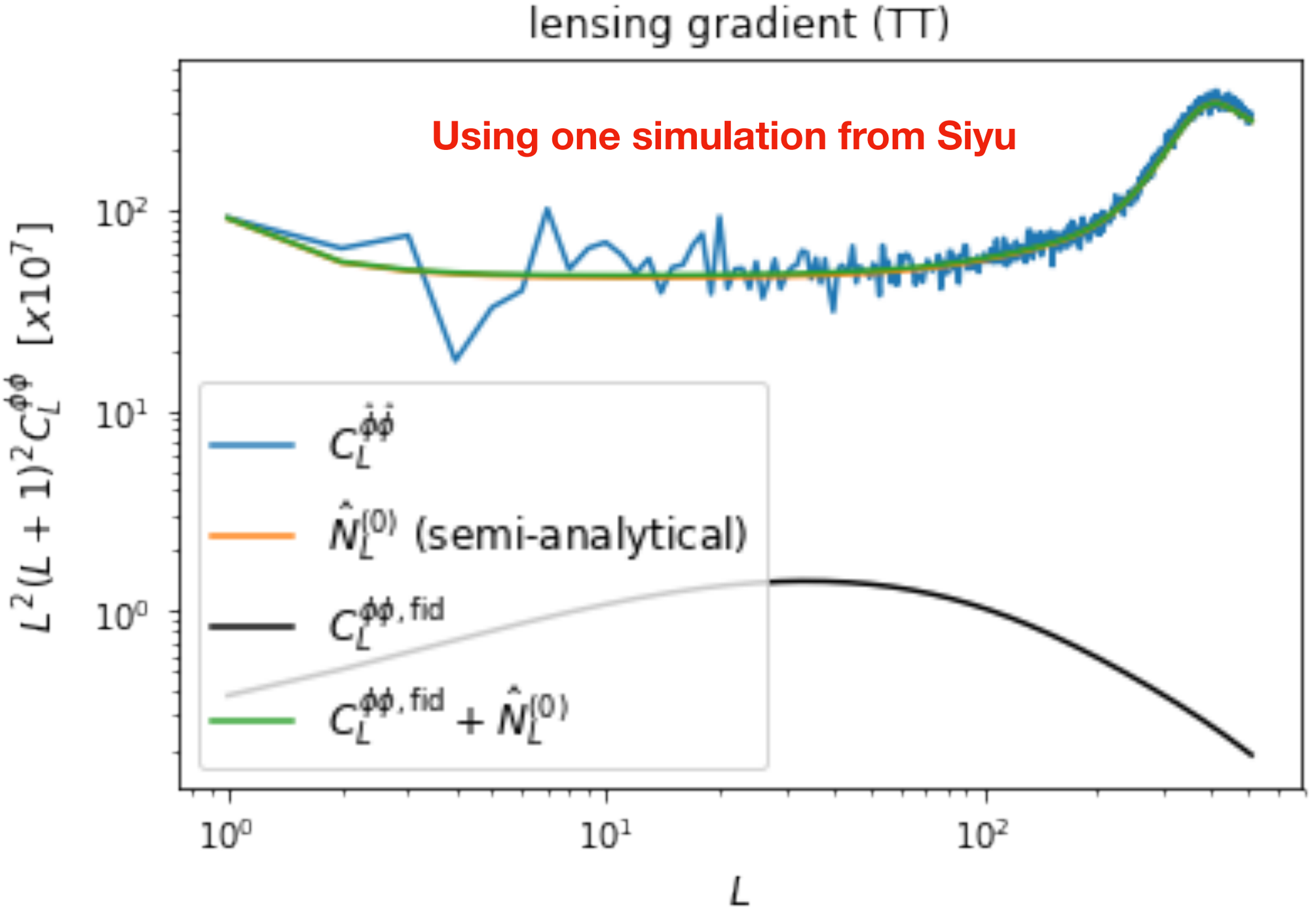

1x10-6
1x10-7
1x10-8
1x10-9
1x10-10
1x10-11
1x10-12
ell*ell*cldd(EB)
EB
100
1000
ell

Curved sky

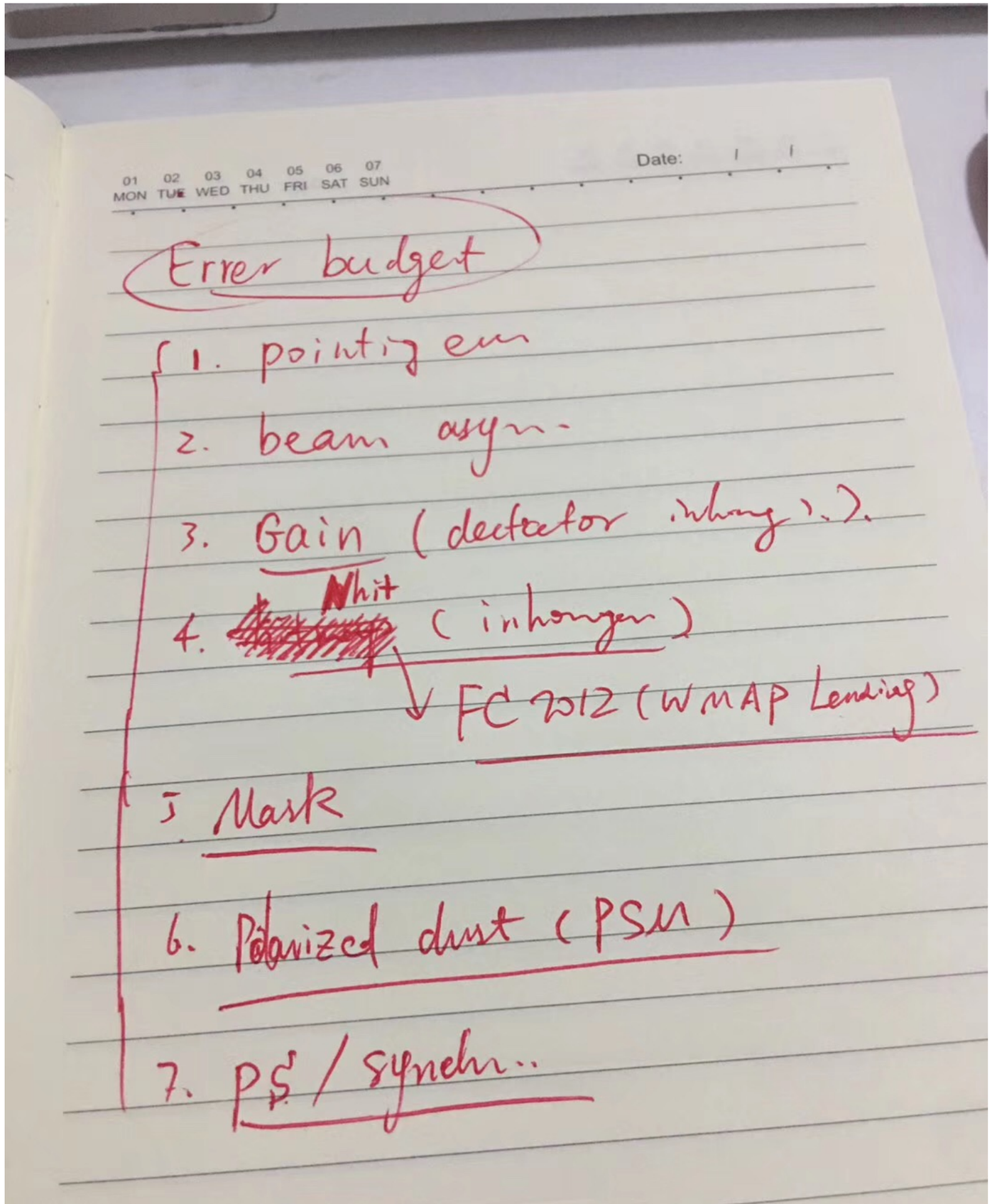
Simulation (from Siyu): 10% sky, 150 GHz noise map, n_side=512



Planck legacy code: Plancklens by Julien Carron



To do list - Simulation



Discussion w. Chang