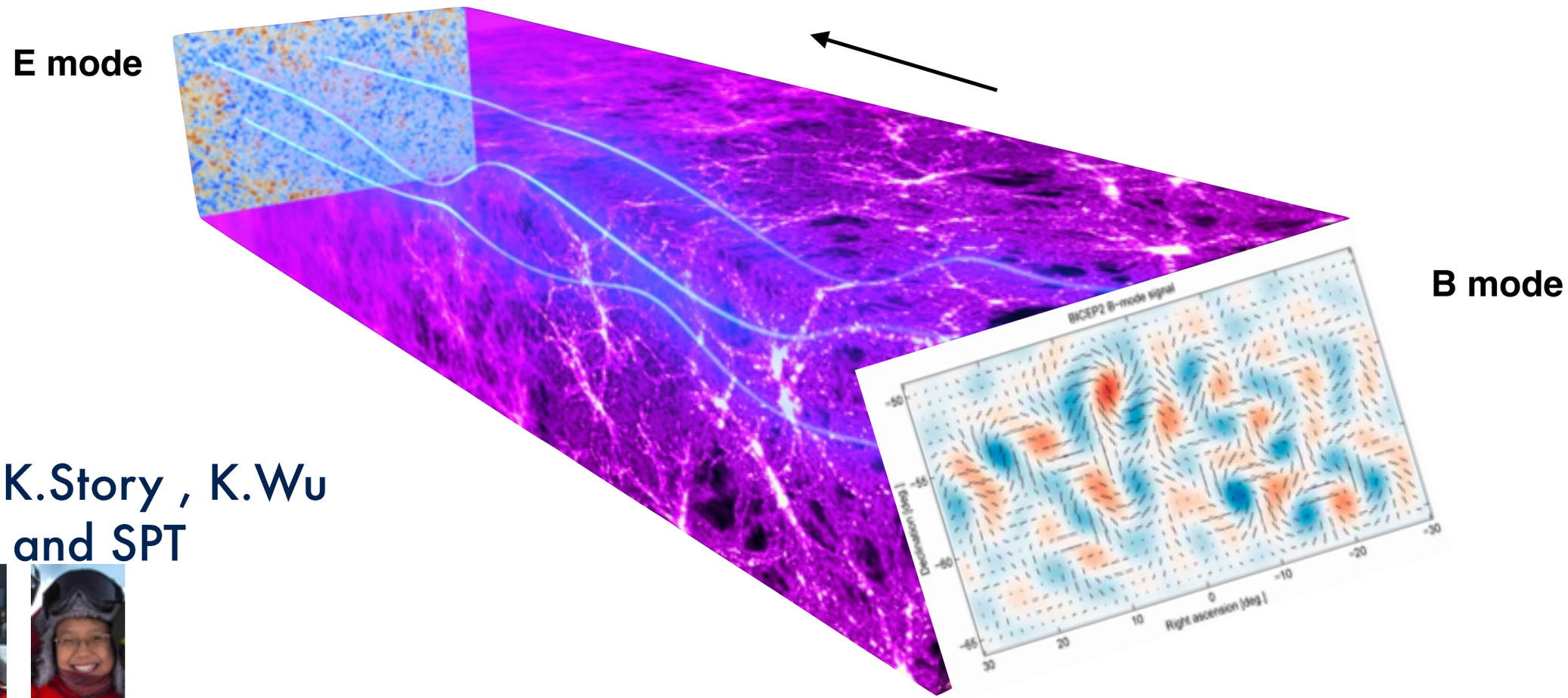
Kavli Institute
for Cosmological Physics
at The University of Chicago

# Delensing CMB B-modes: results from SPT.



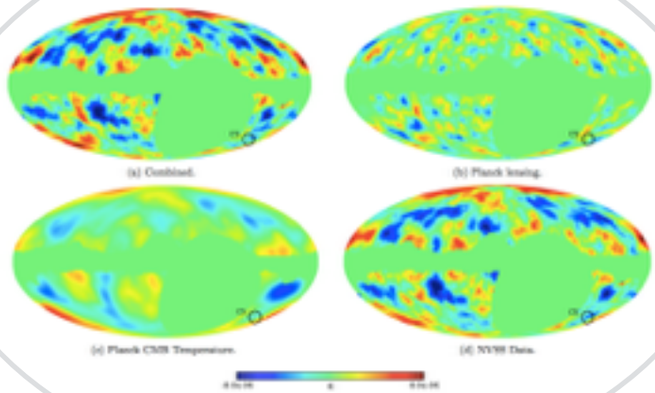

With: K.Story , K.Wu
and SPT


Alessandro Manzotti (KICP-U. Chicago)

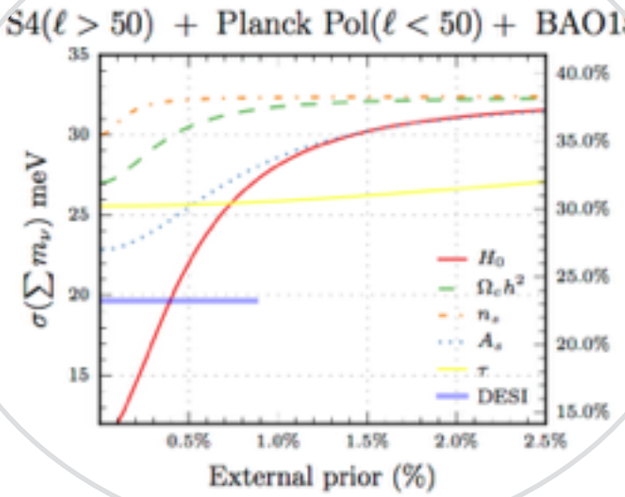
arXiv:1612.———

BCCP talk 25th Oct

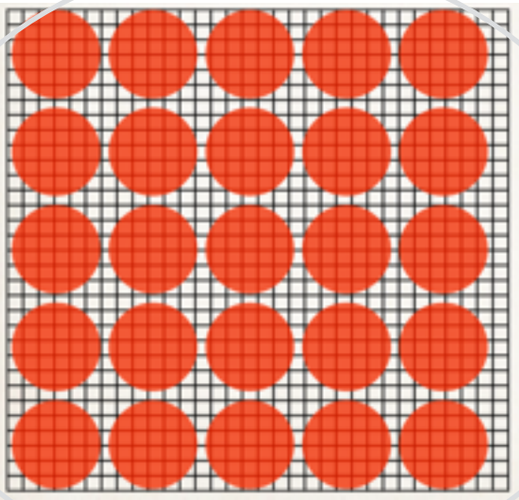
# NOT IN THIS TALK: LSS AND CMB



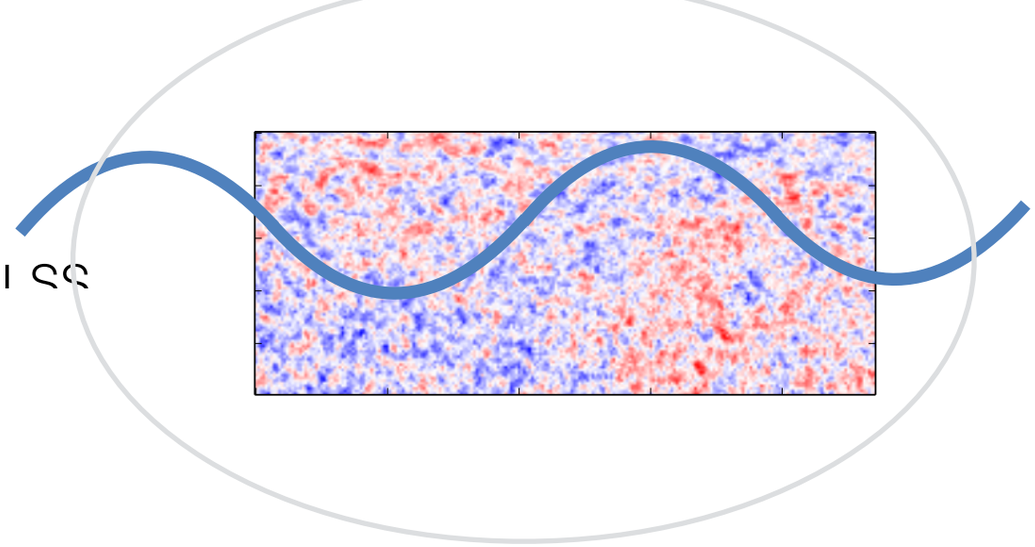
ISW map reconstruction




Future surveys forecast



LargeScaleStructure effective field theory



Super sample effect

CosmoSIS: modular parameter estimation

**Let’s talk !!**

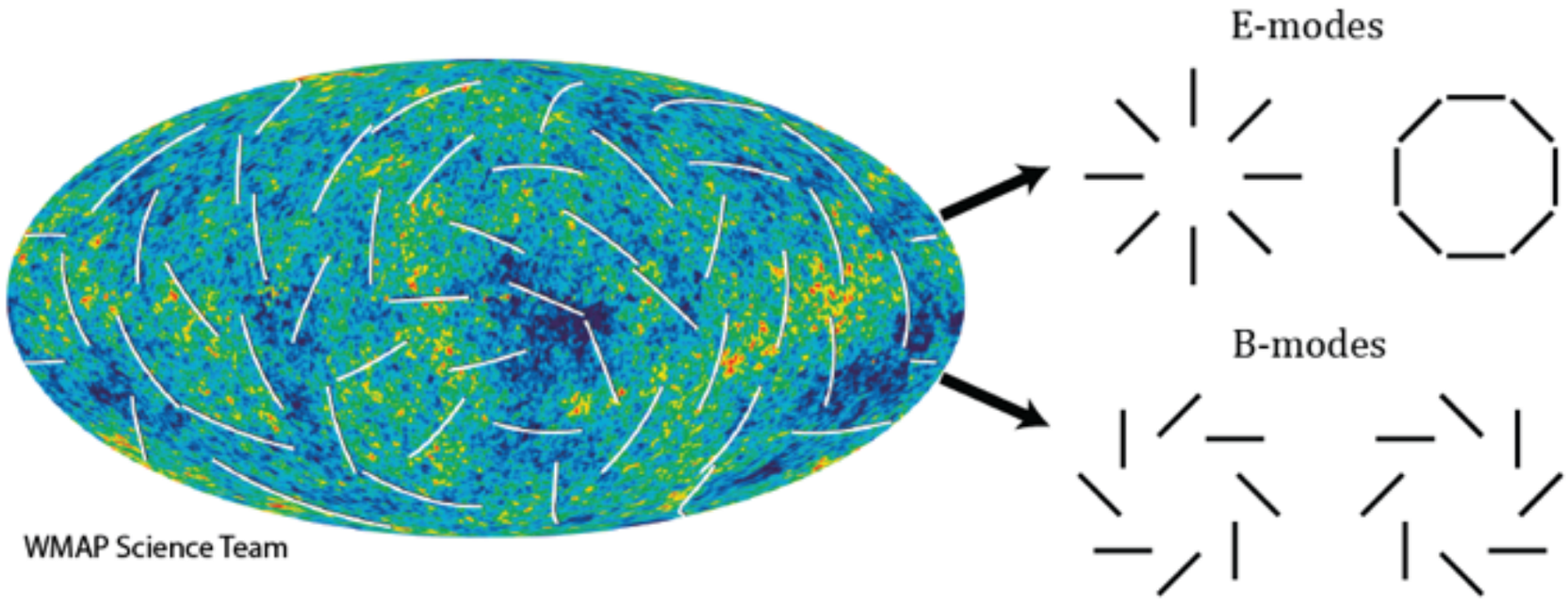
S Dodelson

W, Hu

M. Pietroni

Alessandro Manzotti KICP Chicago

# E-B DECOMPOSITION, DECOMPOSE POLARIZED CMB TO HIGHLIGHT INFLATION




- E mode: produced by scalar anisotropies when CMB photons scatter (recombination and reionization)
- B mode: produced by tensor (gravity waves) anisotropies when CMB photons scatter (recombination and reionization)
- B mode: produced by lensing. “Turning” E mode into B mode

Kamionkowski, Kosowsky, Stebbins (1997)
Zaldarriaga & Seljak (1997)

$\mathrm{T}(\hat{n})\ (\pm 350\mu K)$

Unlensed

$\mathrm{E}(\hat{n})\ (\pm 25\mu K)$

$\mathrm{B}(\hat{n})\ (\pm 2.5\mu K)$

(no primordial B-modes)

$\mathrm{T}(\hat{n})\ (\pm 350\mu K)$

Lensed

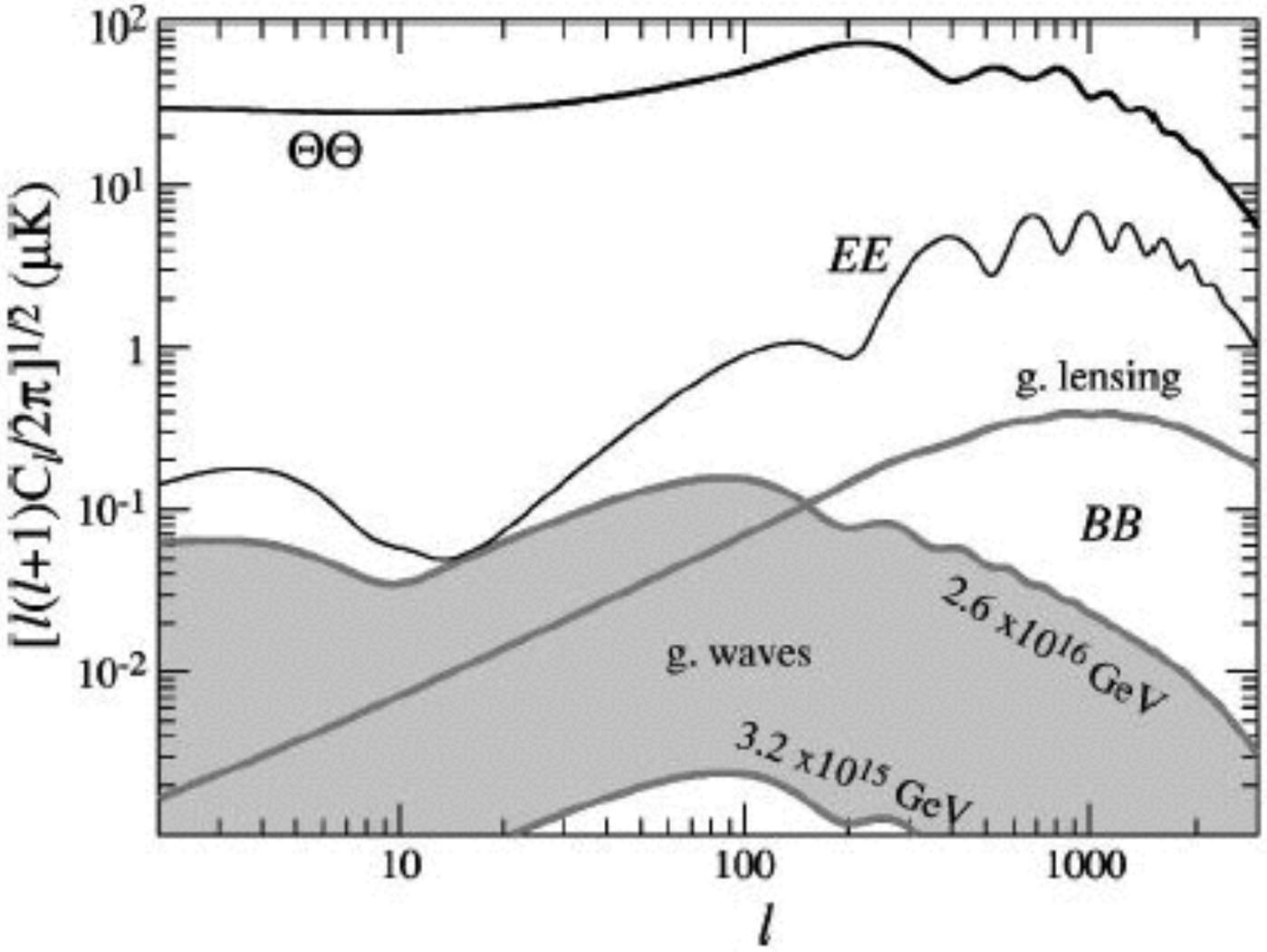
$\mathrm{E}(\hat{n})\ (\pm 25\mu K)$

$\mathrm{B}(\hat{n})\ (\pm 2.5\mu K)$

(no primordial B-modes)

# B-MODE LENSING SPECTRUM

Angular scale




Power

# DELENSING IS CRUCIAL

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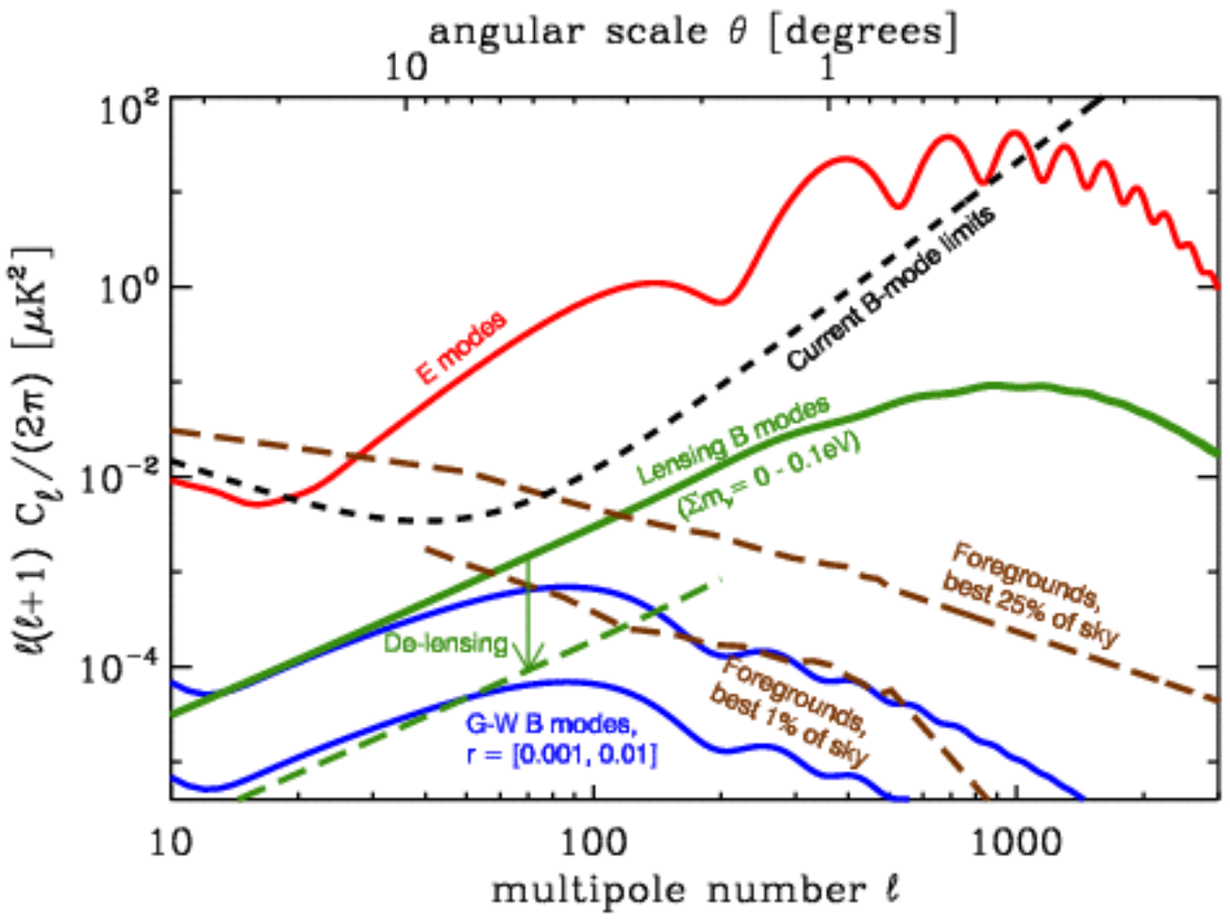
# CRUCIAL

**In 10 years (CMB Stage 4) it could be the main source of noise for primordial B mode signal.**

- It can be seen as a white noise component at ~5 uK-arcmin.
- Not cleanable with multi frequencies.
- Well modeled, but cosmic variance would be a problem



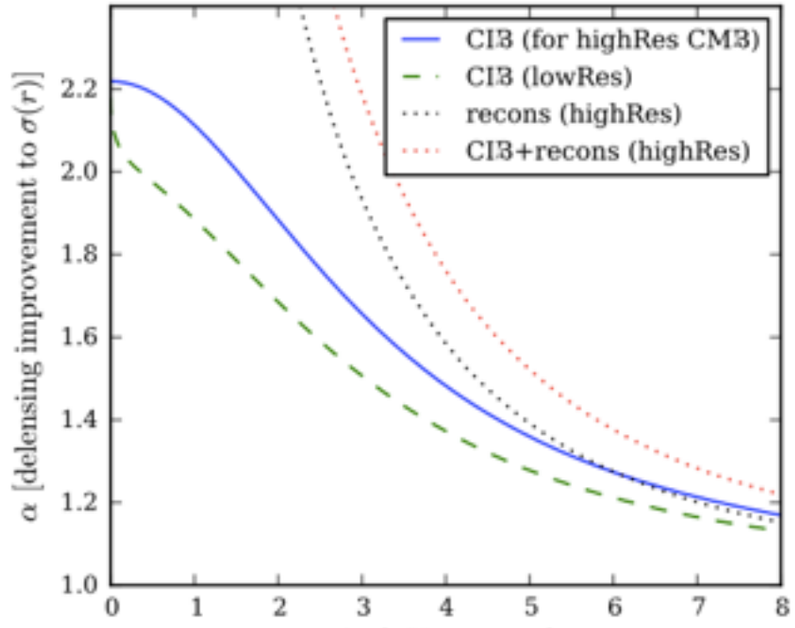

Abazajian, K.N. *et al.*

# NO SURPRISE: IT WILL LIMIT INFLATIONARY CONSTRAINTS AND MORE

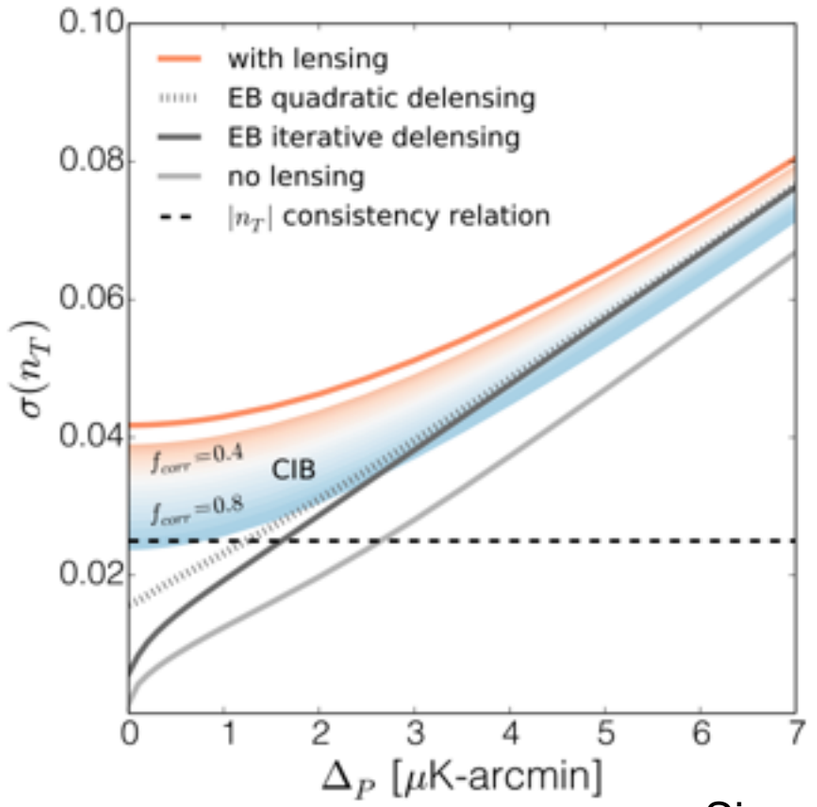
- Our constraint on the inflationary tensor perturbation and tilt will depend on it

- It will limit lensing reconstruction (a.k.a as iterative delensing)

- It will limit parameter that depends on peak position and damping tail information like N_eff

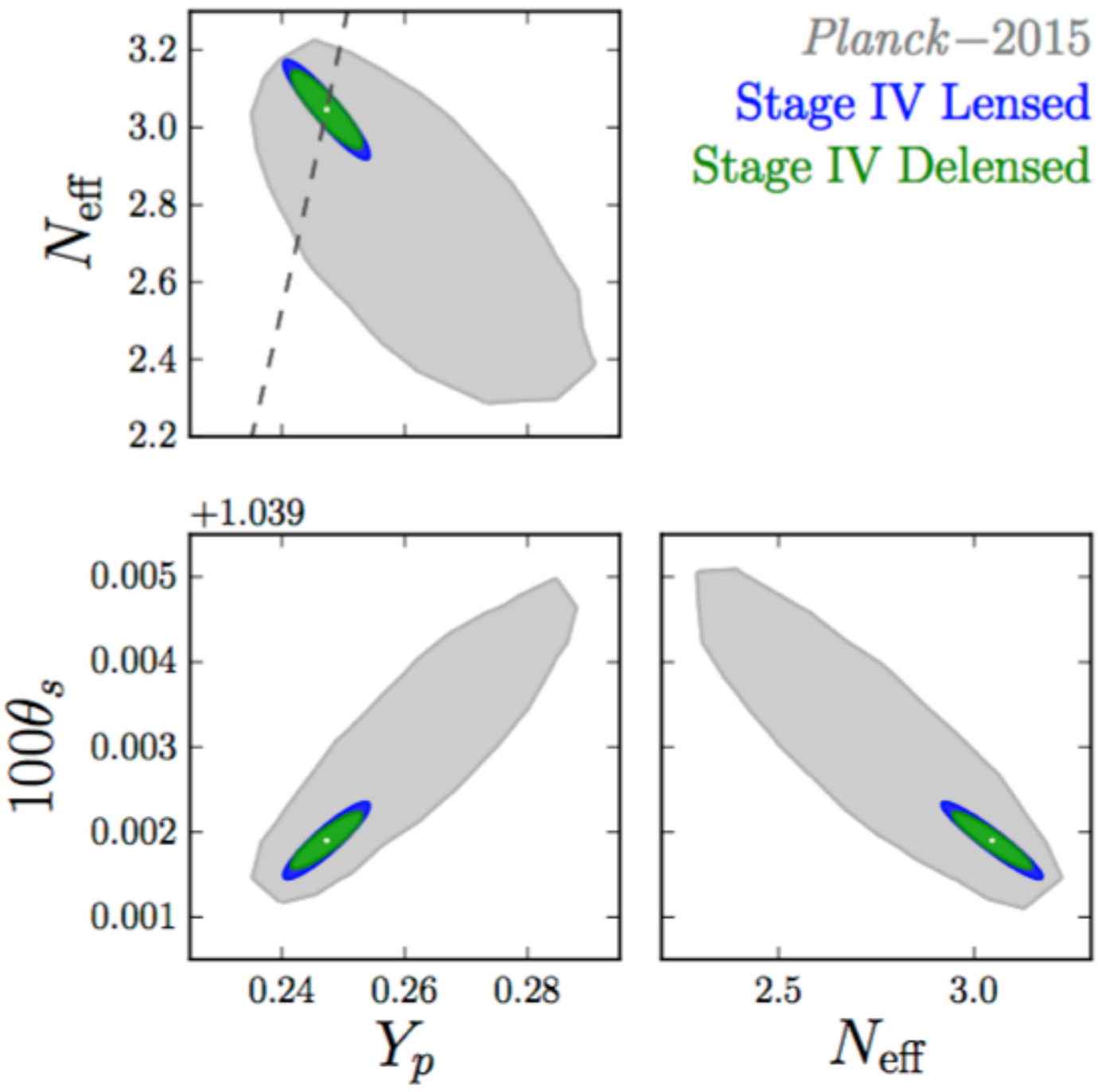



Sherwin Schmittfull.




Simard

# ... AND MORE




*Planck*−2015
Stage IV Lensed
Stage IV Delensed

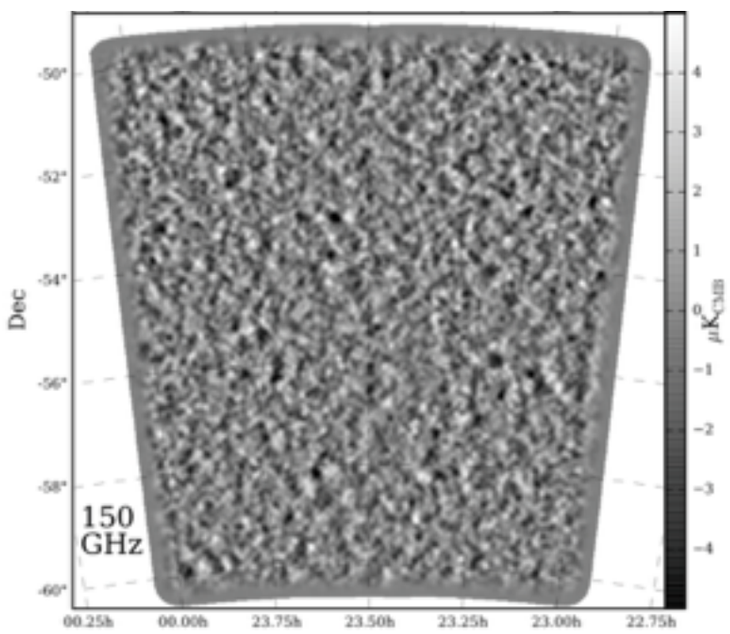
Green, Meyers, van Engelen

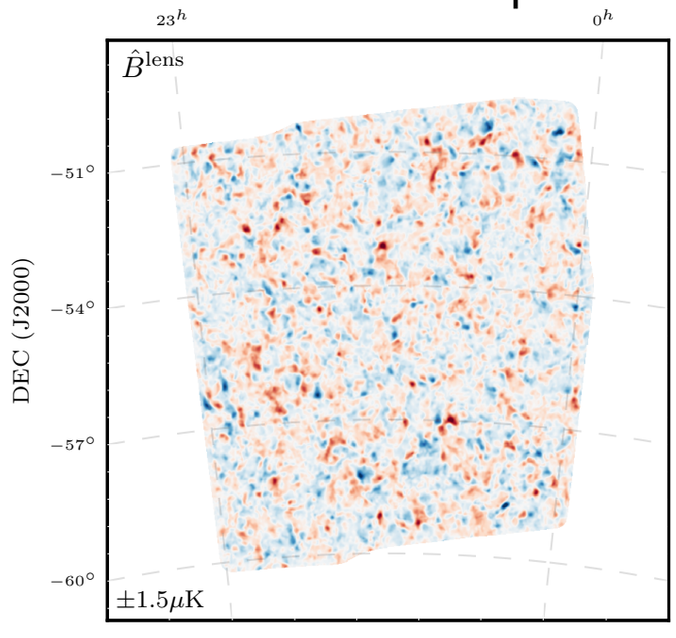
# WHAT CAN WE DO? BUILD A TEMPLATE AND REMOVE!

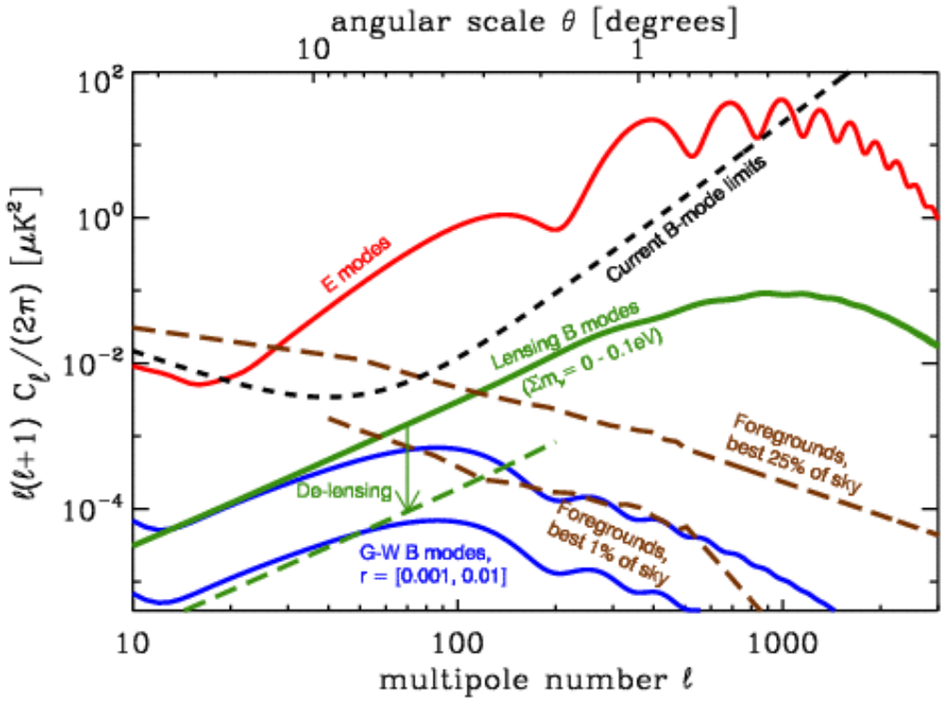
B-mode data

B-mode template $E \otimes \phi = B_{lens}$

$$\left( \quad - \quad \right)^2$$



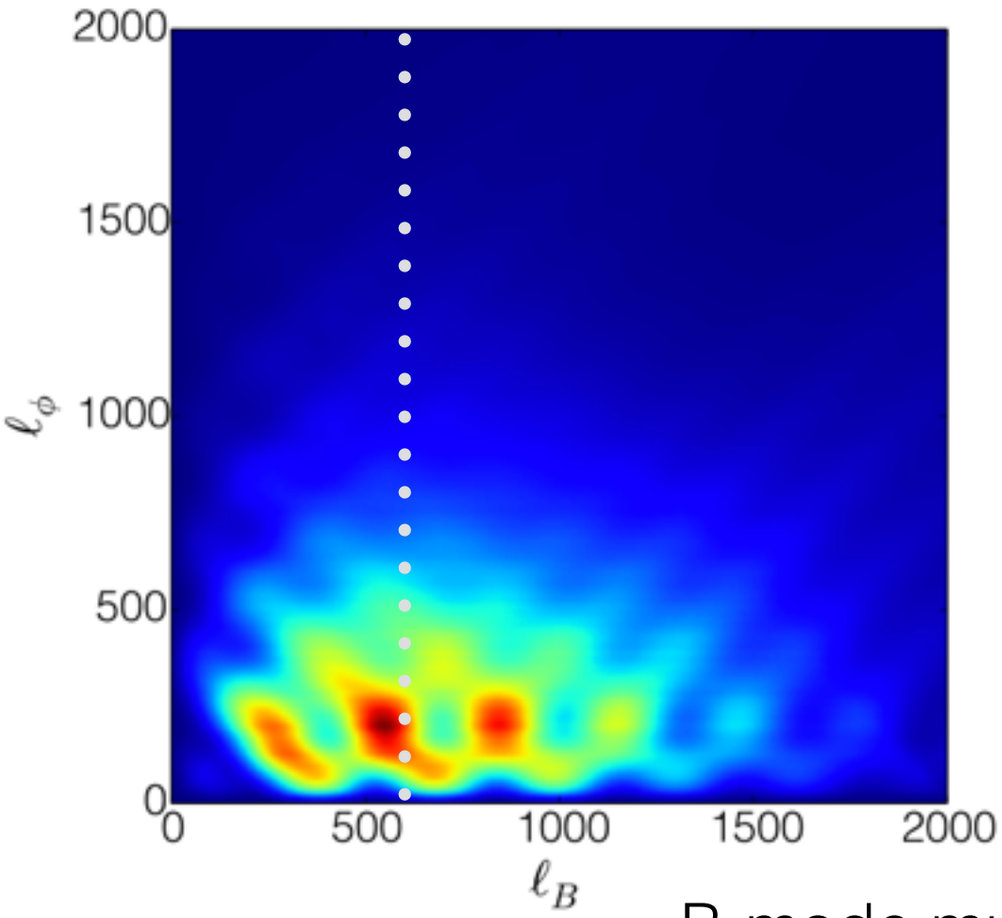



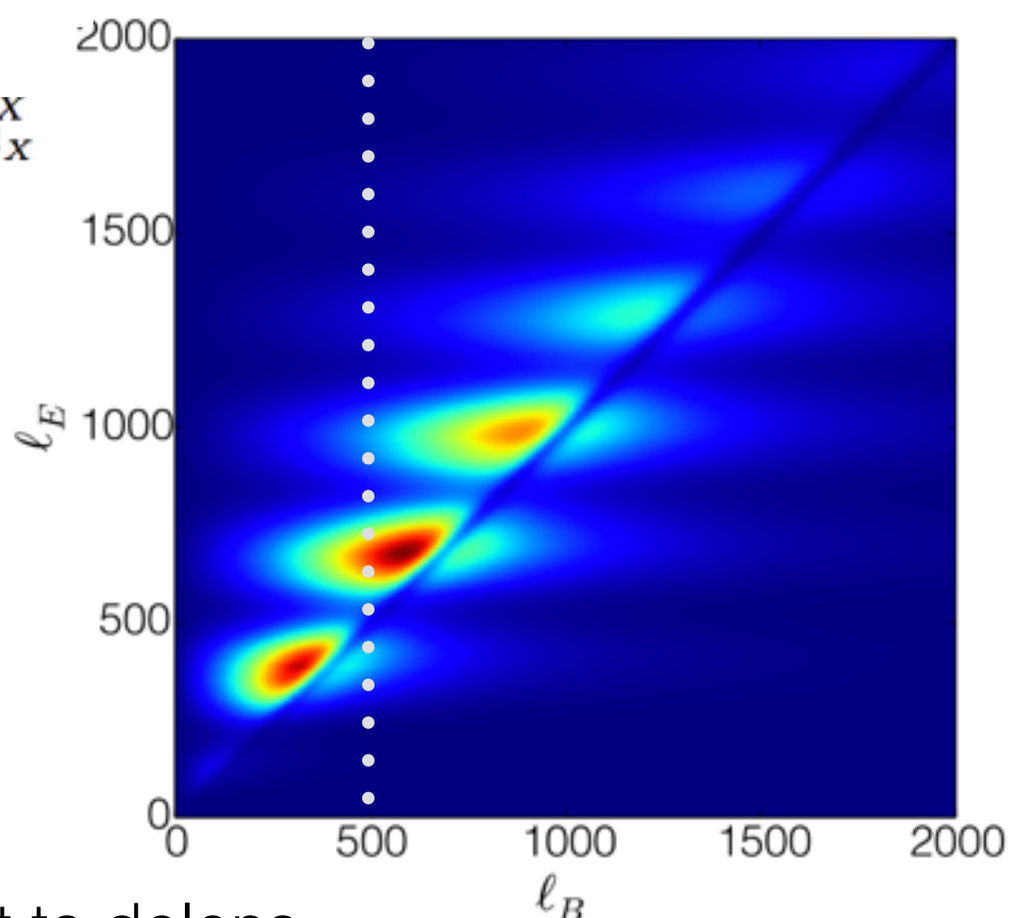
# TEMPLATE: WHAT MODES DO WE NEED?

$$E \otimes \phi = B_{lens}$$

$\phi =$ Integral of structures along the line of sigh




$$l_B(\partial C_{l_B}^B / \partial C_{l_X}^X) C_{l_X}^X$$




B-mode multiple you want to delens

Simard,Hanson,Holder 2014

- Mainly from large scale potential l>100
- E_mode from scales slightly smaller than B_lens

# HOW CAN WE GET THOSE MODES?

Your favorite CMB experiment ⟵ $E \otimes \phi = B_{lens}$

**We want**

**Kernel overlap**

**Low Noise**

## CIB

Cosmic Infrared Background

The **best method right now.** Already used on data by SPT (Hanson B-modes paper). CIB model uncertainties not limiting now, you can marginalize over it (Sherwin Schmittfull.)

## CMB

In the **future** it will be the **best source** of phi reconstruction. Not there yet but already powerful if combined with the CIB

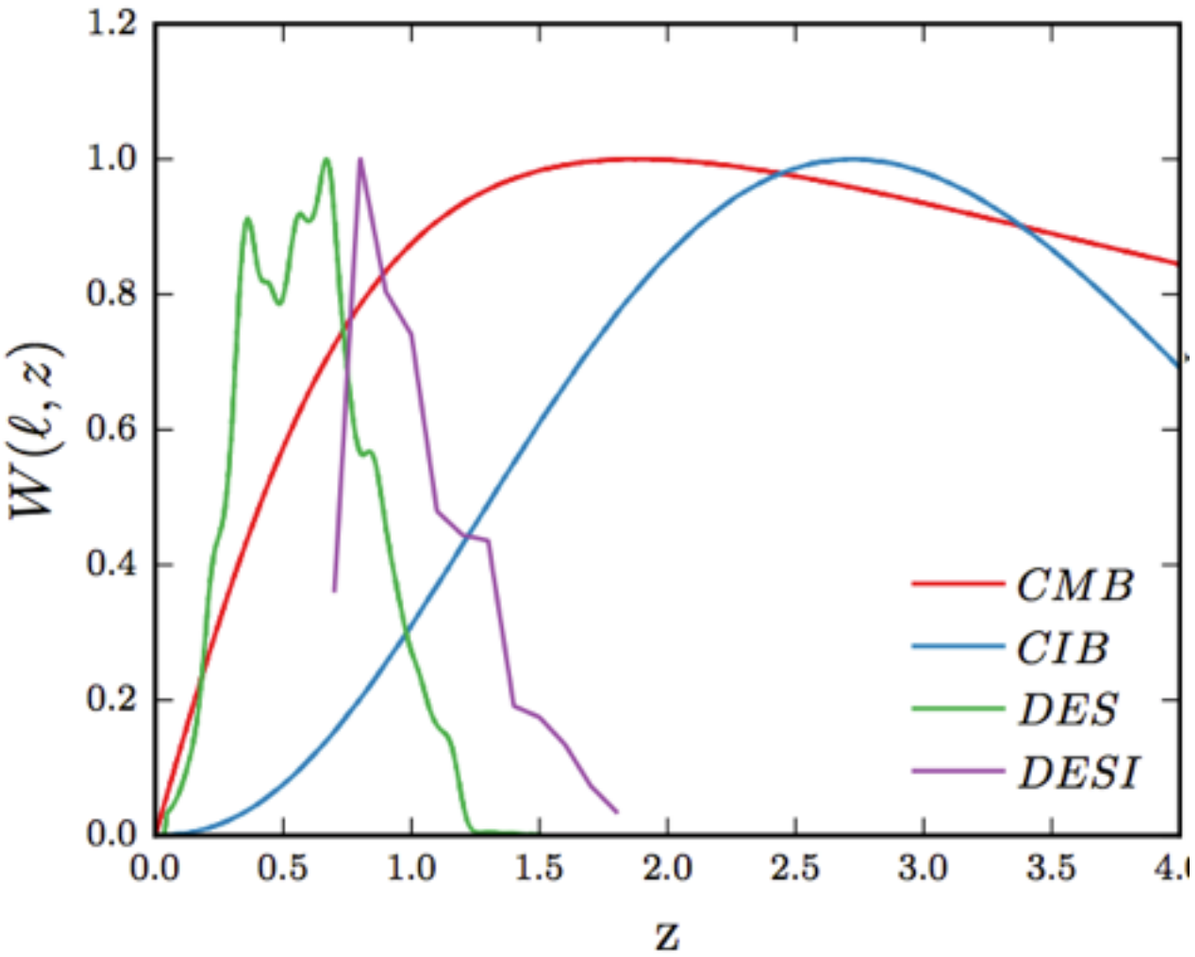
## Galaxies

Low redshift. They do not probe well the sources that lens the CMB. Maybe useful to check for systematics.

SKA?

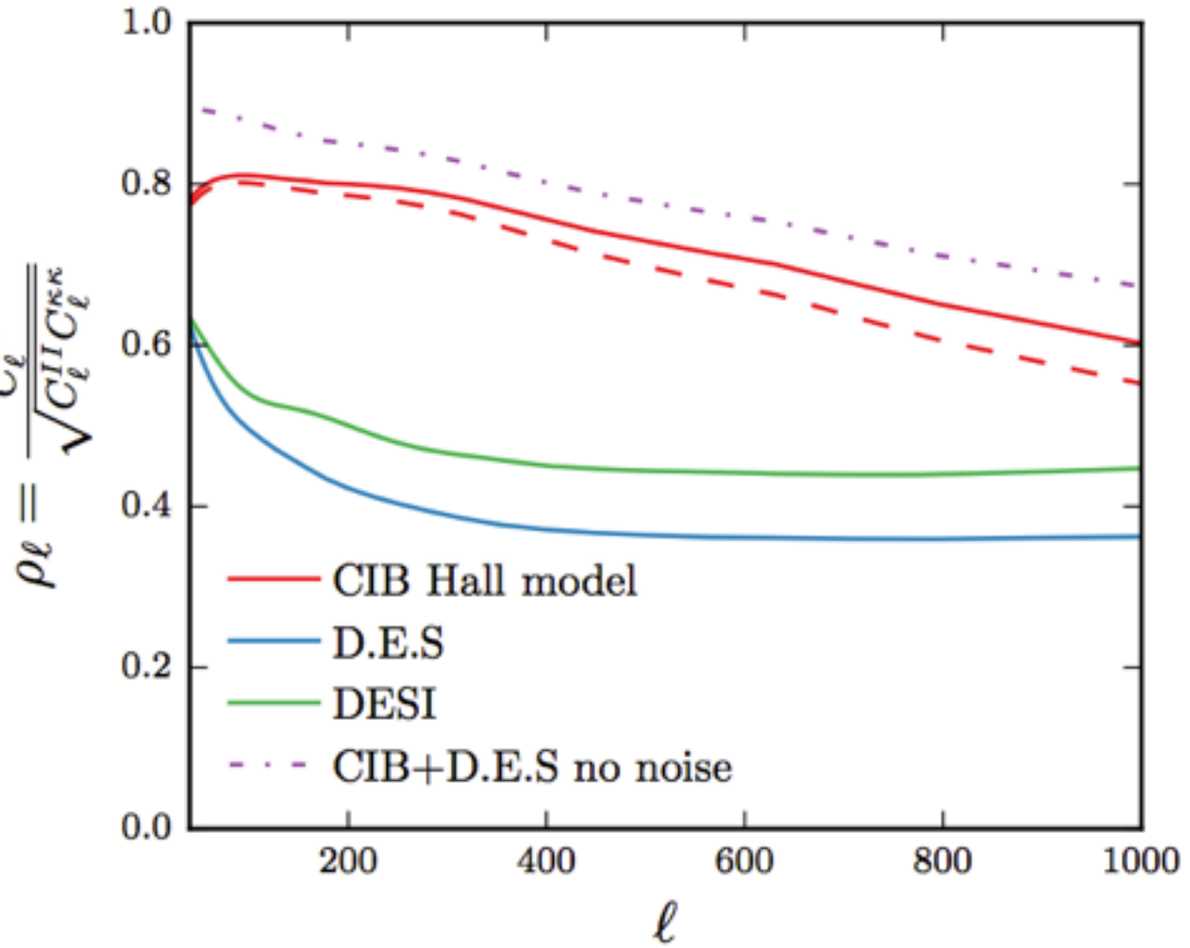
# OPTIMAL SOURCE FOR A LENSING MAP?

Where the lenses are




Redshift

How much are they correlated with lensing considering noise




Angular Scale

# DELENSING IS CRUCIAL, FEASIBLE  BUT HARD.

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# HOWEVER A NEW PHASE IS BEGINNING:

# WE ARE NOW DELENSING

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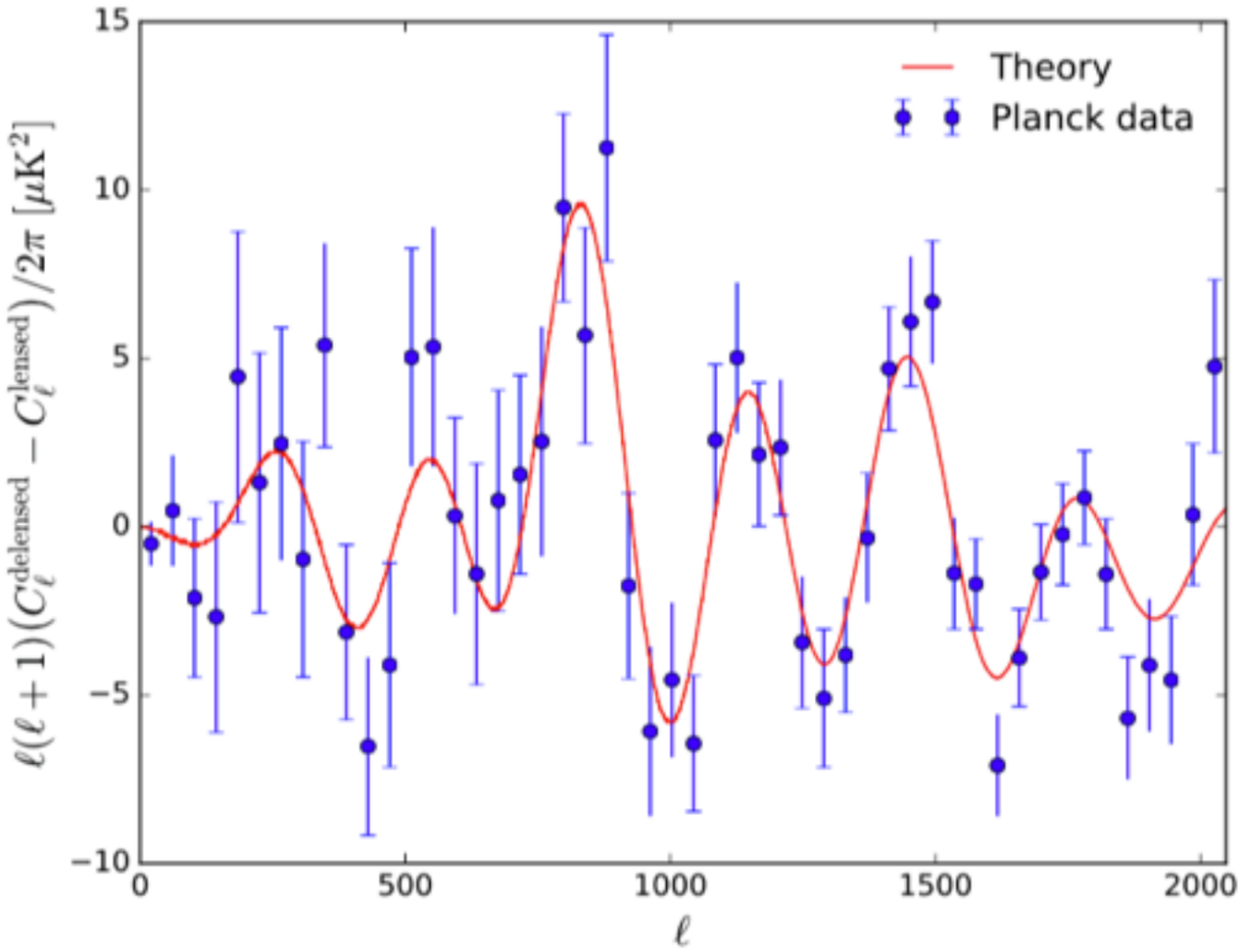
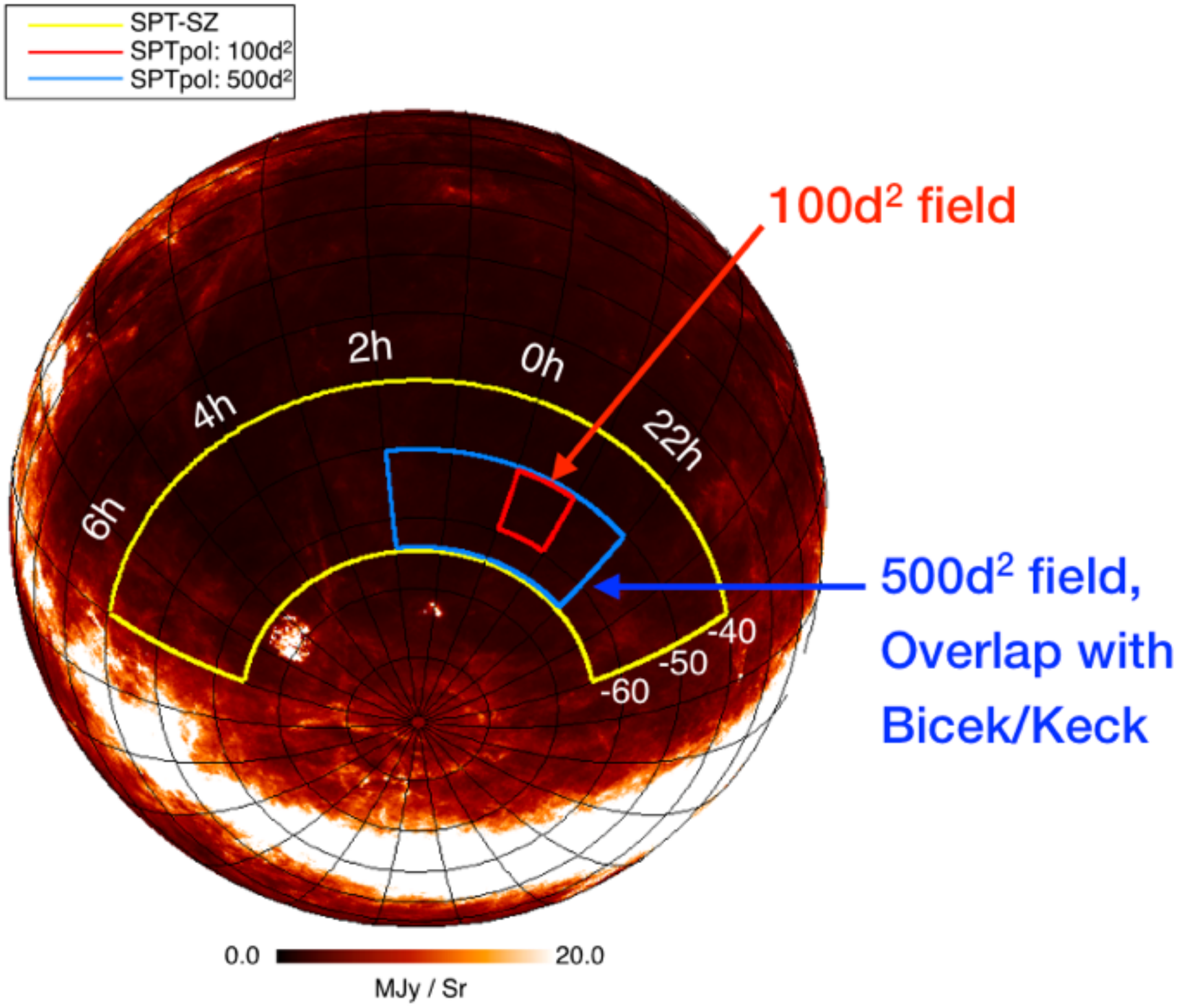
# A (QUITE LOCAL) SUCCESS IN TEMPERATURE

Real space CIB delensing of Planck TT data.



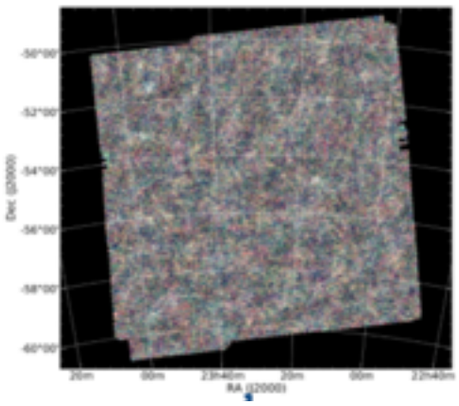

Patricia Larsen, Anthony Challinor, Blake D. Sherwin, Daisy Mak

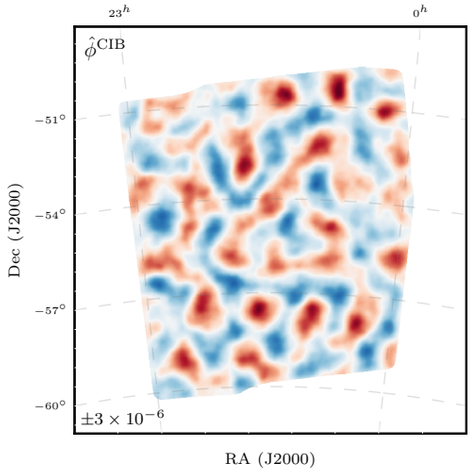
# THE SOUTH POLE TELESCOPE STORY, DELENSING THE B-MODES



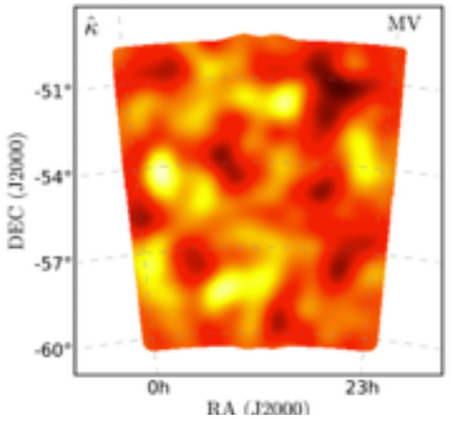
# THE SPT STORY, THE DATA

- CIB map, from Herschel 500μm map.

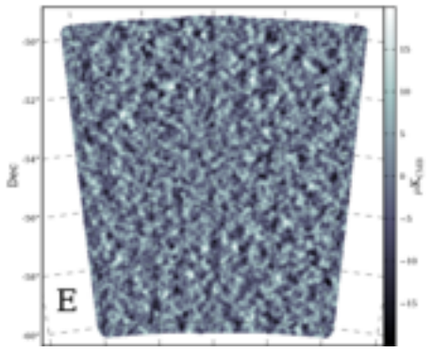


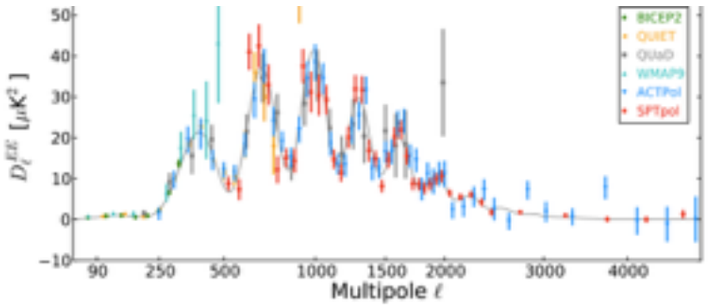




Internal CMB slightly worse

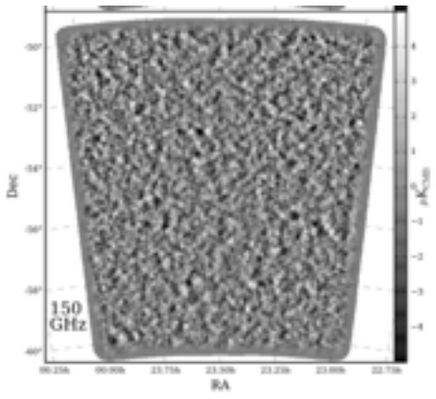


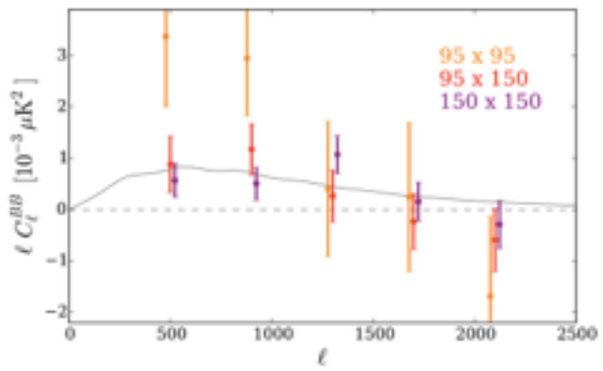

- E mode (Crites, SPT 2015)




- B mode (Keisler, SPT 2015)



# B TEMPLATE: THE PIPELINE

Construct a lensing template from the CIB map

$$\hat{\phi} = C_\ell^{CIB-\phi}(C_\ell^{\phi\phi}C_\ell^{CIB-CIB})^{-1} \; T_\ell^{CIB}$$

Filter the E-mode map with a C-inv Wiener filter: $\ell^x_{\rm min} \;\; \ell_{\rm max}$

Build a B template

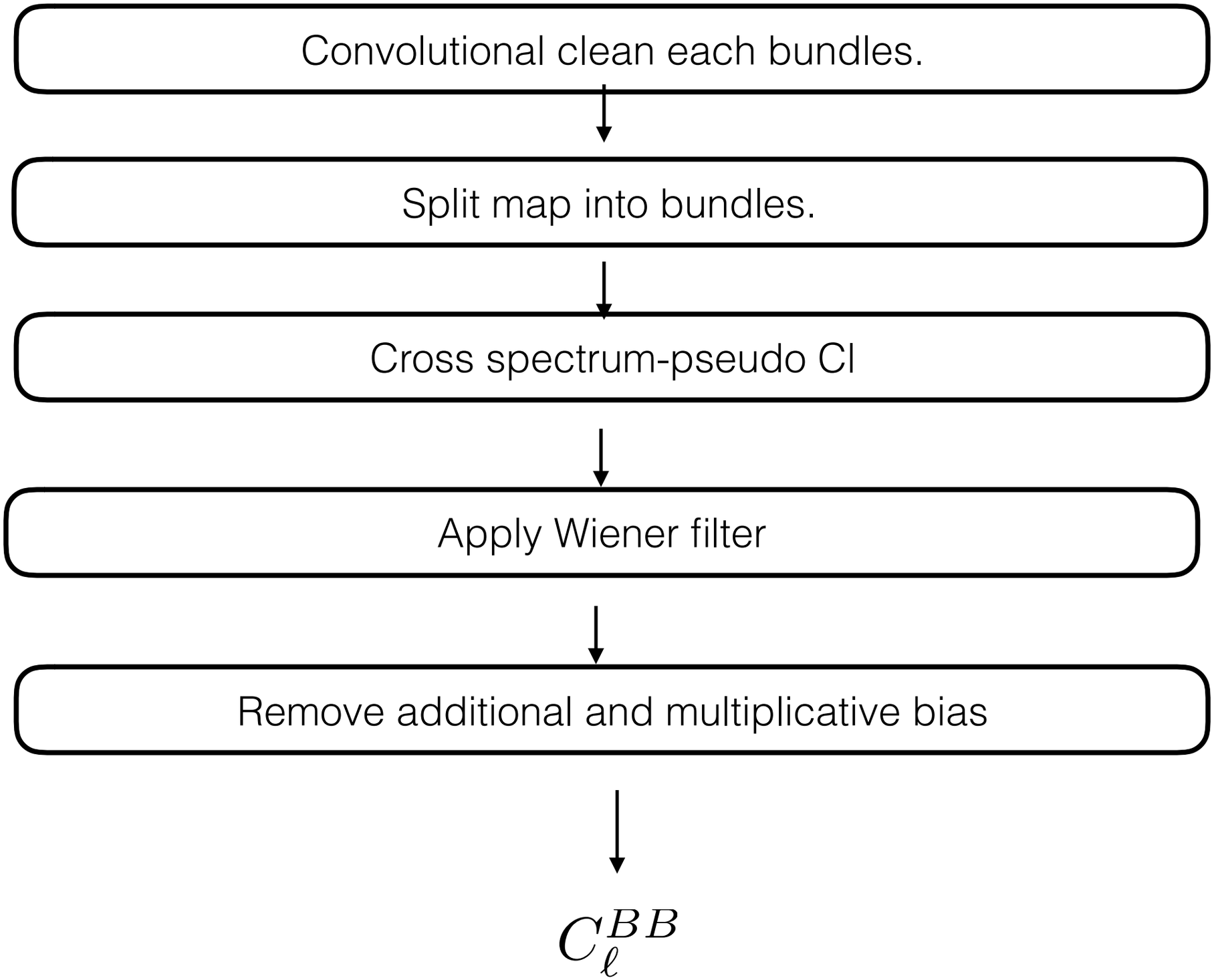
$$B^{\rm lens}(\mathbf{l}) = \int \frac{d^2\mathbf{l}'}{(2\pi)^2} W(\mathbf{l},\mathbf{l}')E(\mathbf{l}')\kappa(\mathbf{l}-\mathbf{l}')$$

Make it as similar as possible to the data. Apply Transfer function

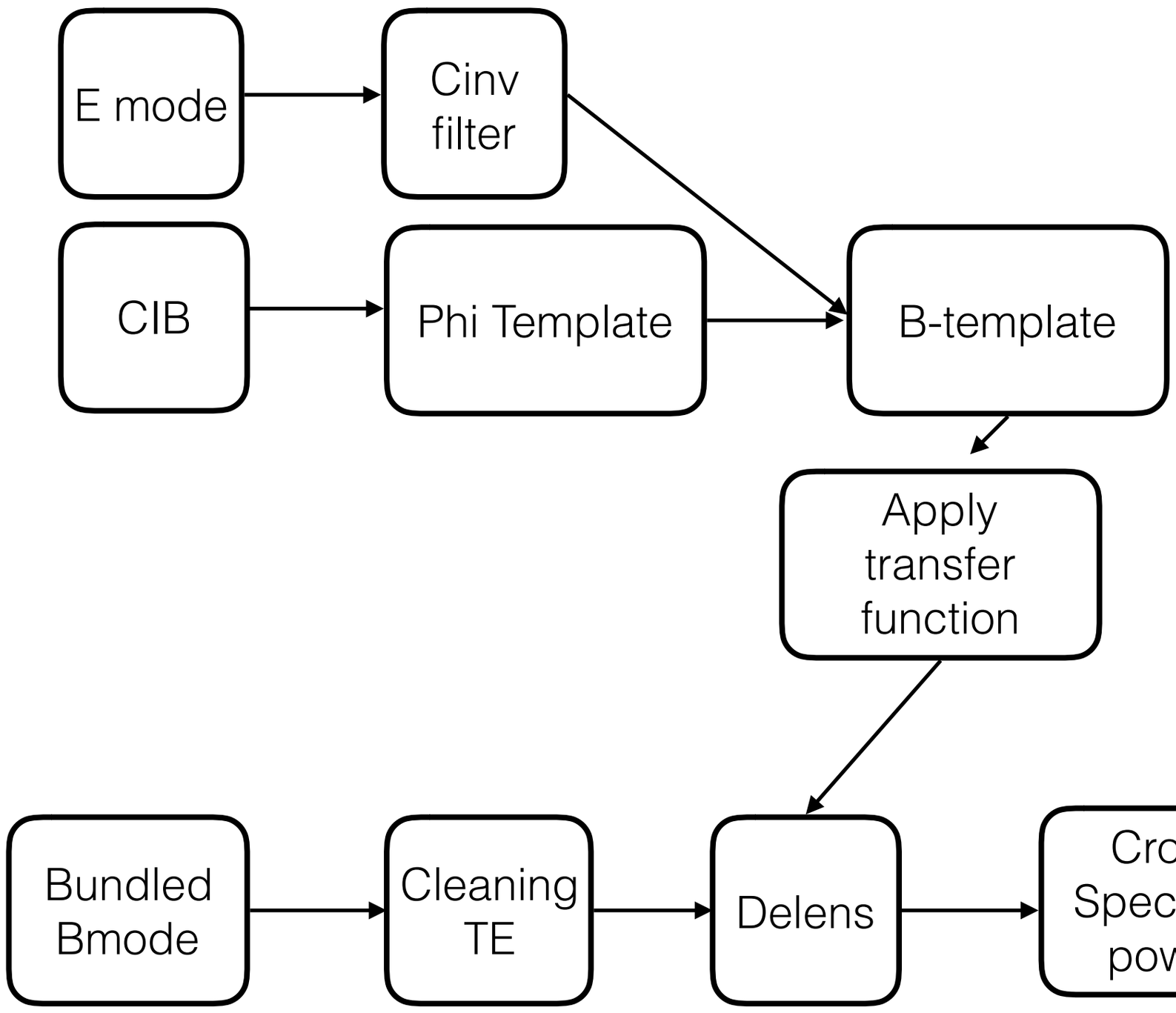
$$\bar{B}_{\rm lens}$$

Note: This is a signal to noise filtered template

# BB POWER: THE PIPELINE



# PUTTING THEM TOGETHER : DELENSING PIPELINE




Note: The subtraction happen in Fourier space

$$B^{\rm res}(\ell) = B^{\rm lens}(\ell) - \hat{B}^{\rm lens}(\ell)$$

# DATA

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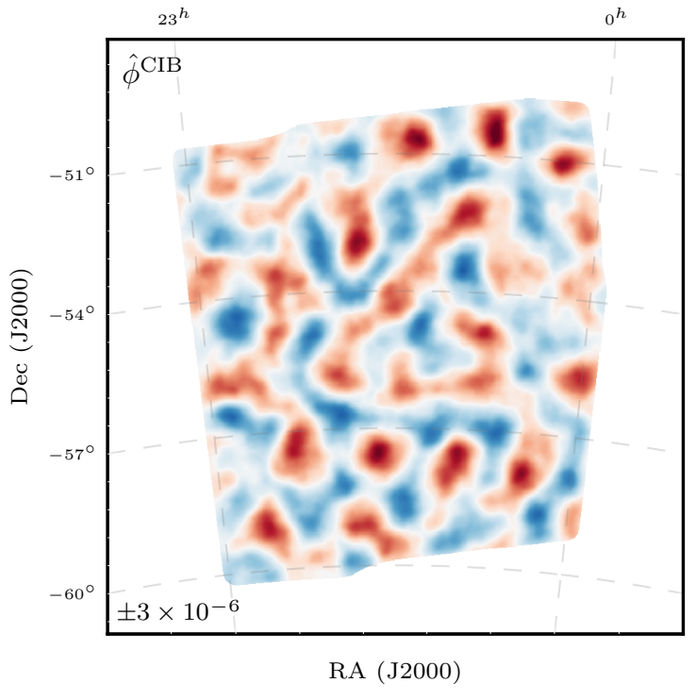
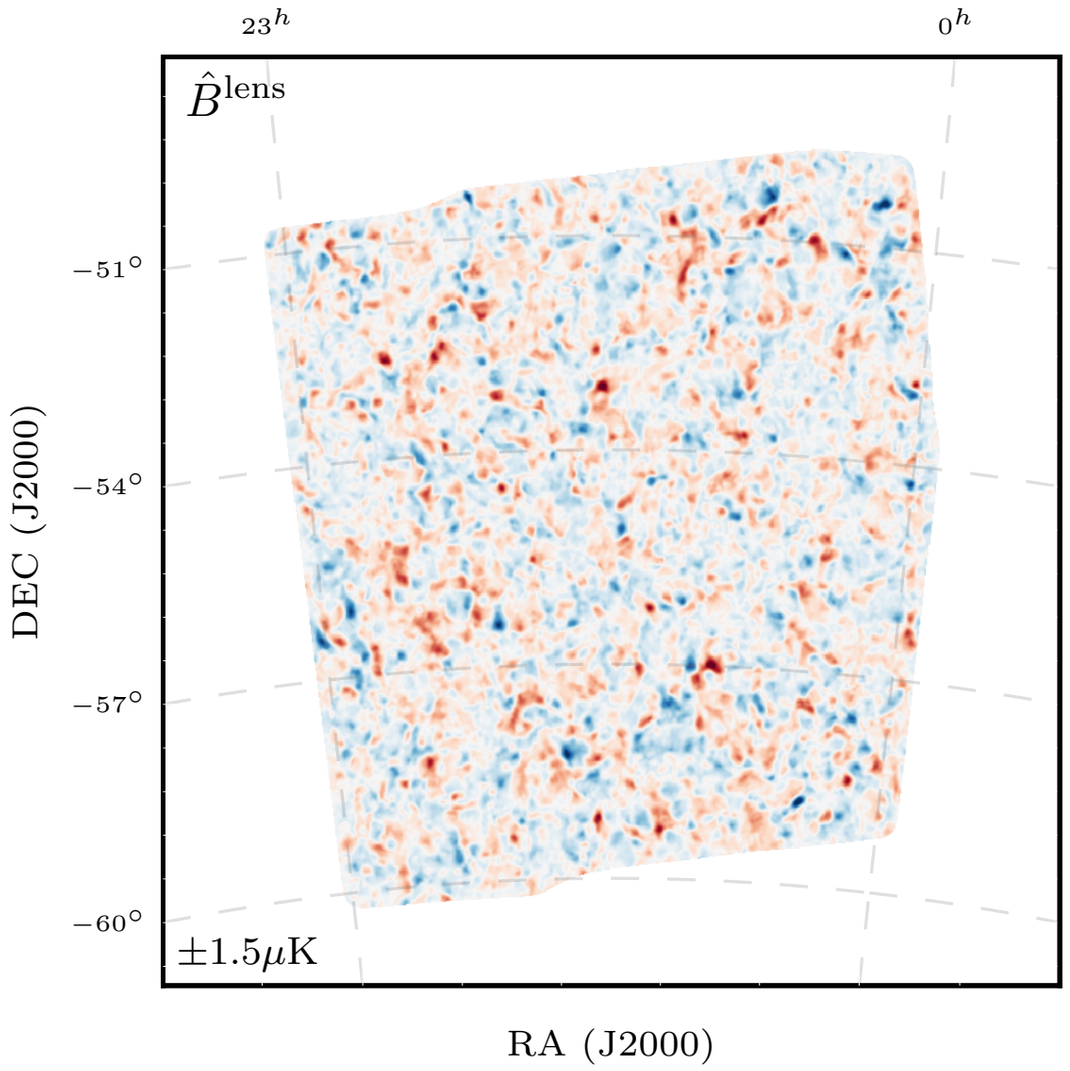
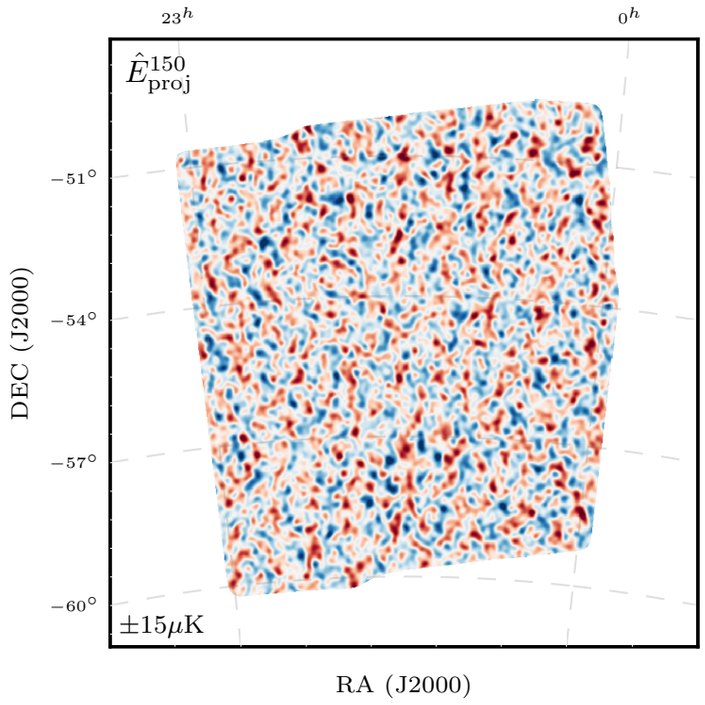
# SPT 15-20% DELENSING: THE MAPS

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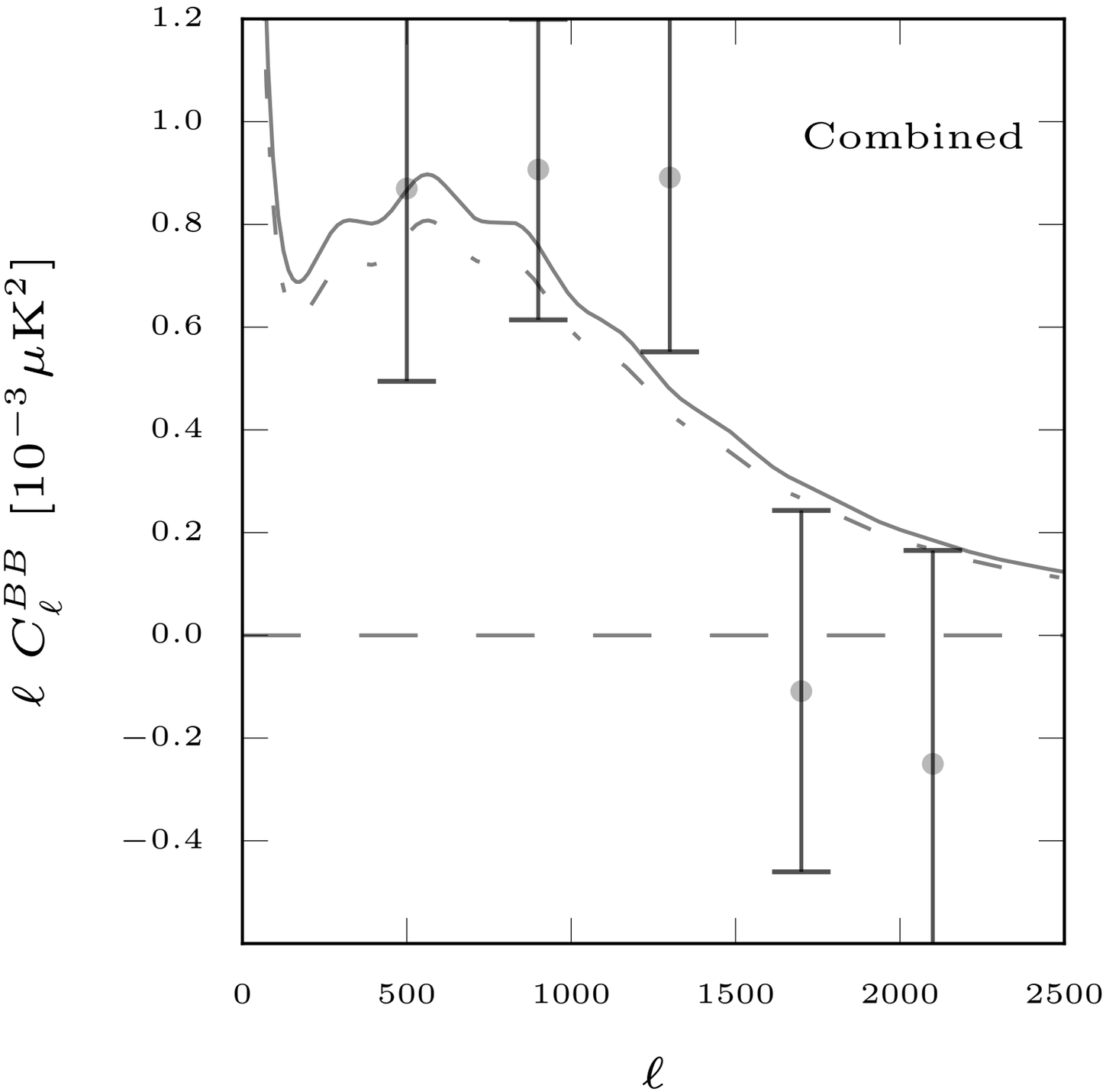
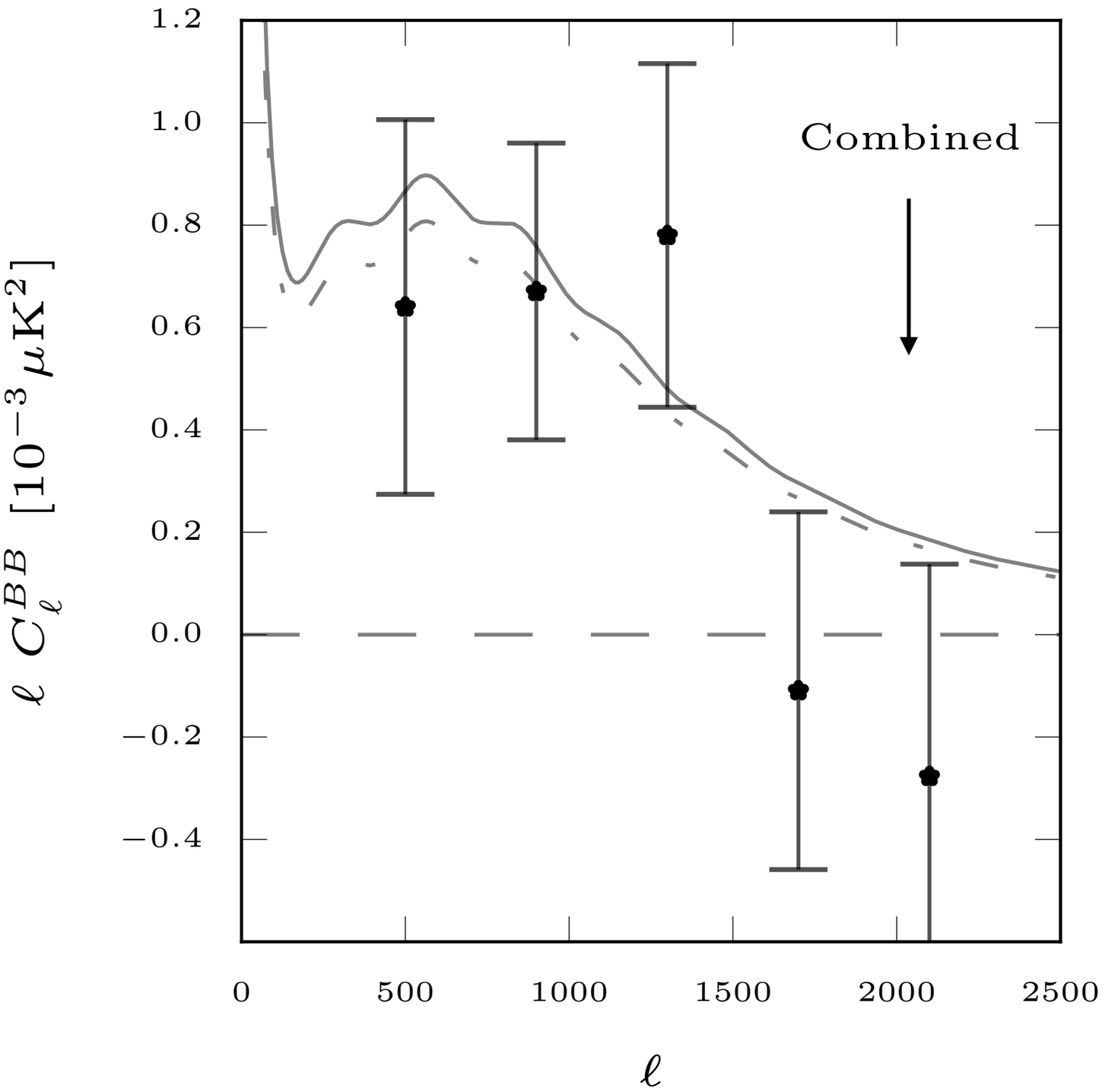
Work 2 years on simulations, filtering …

# SPT 15-20% DELENSING: THE BAND POWERS



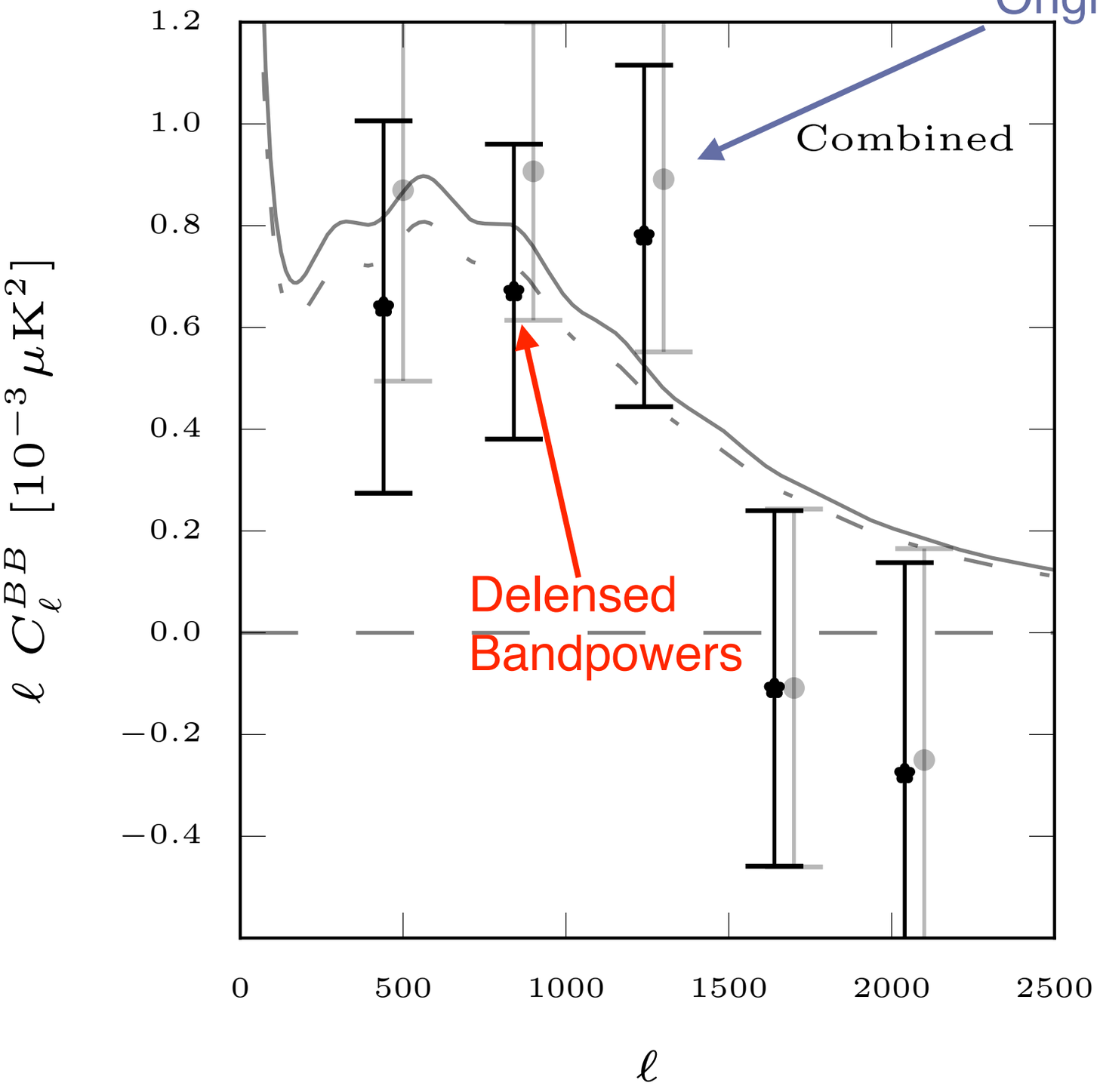
# SPT 15-20% DELENSING: THE BAND POWERS



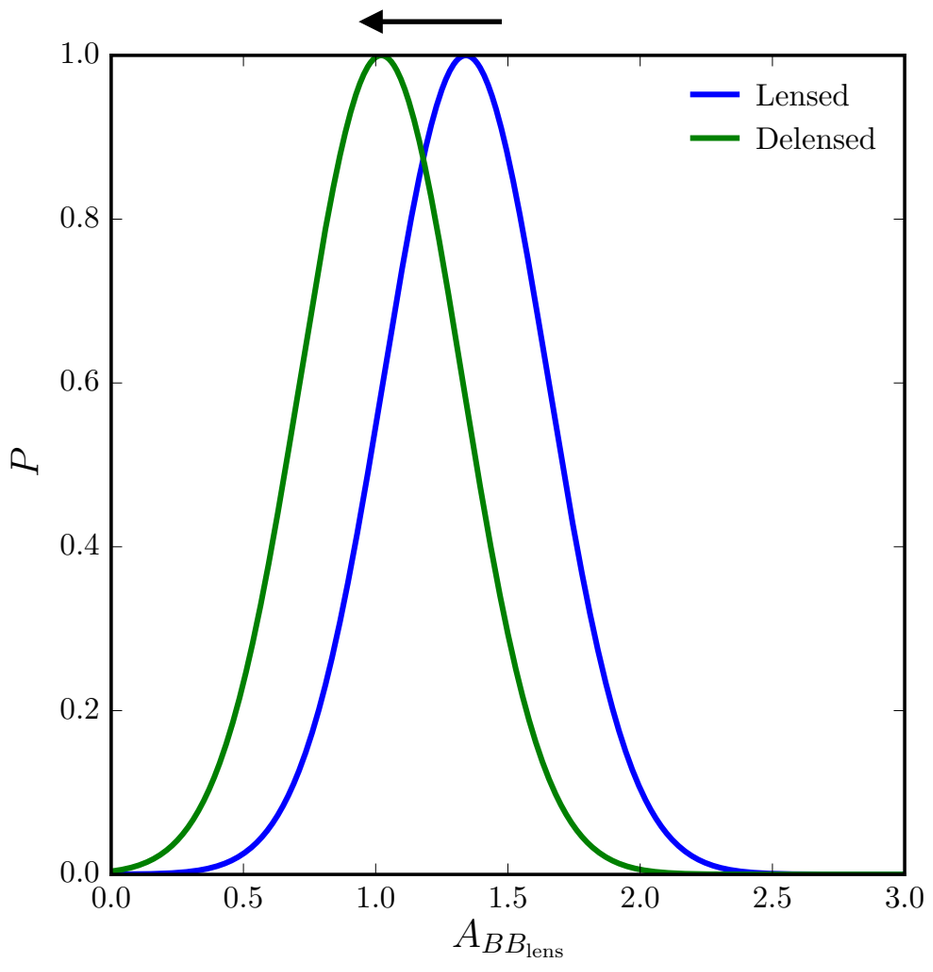

Delens

# SPT 15-20% DELENSING: THE BAND POWERS

Original Bandpowers




$$A_{\rm lens} = 1.34 \pm 0.31$$
$$A_{\rm delens} = 1.02 \pm 0.30$$

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slides at:

# SPT 10% DELENSING: THE SYSTEMATIC TESTS

Run and passed so far

Low-ell cut in E mode: important push as low as possible

High-ell cut in E mode

CIB model assumed

Curl Estimator

Noise only maps

# AND THE FUTURE WILL BE EVEN BRIGHTER, DELENSING WILL IMPROVE

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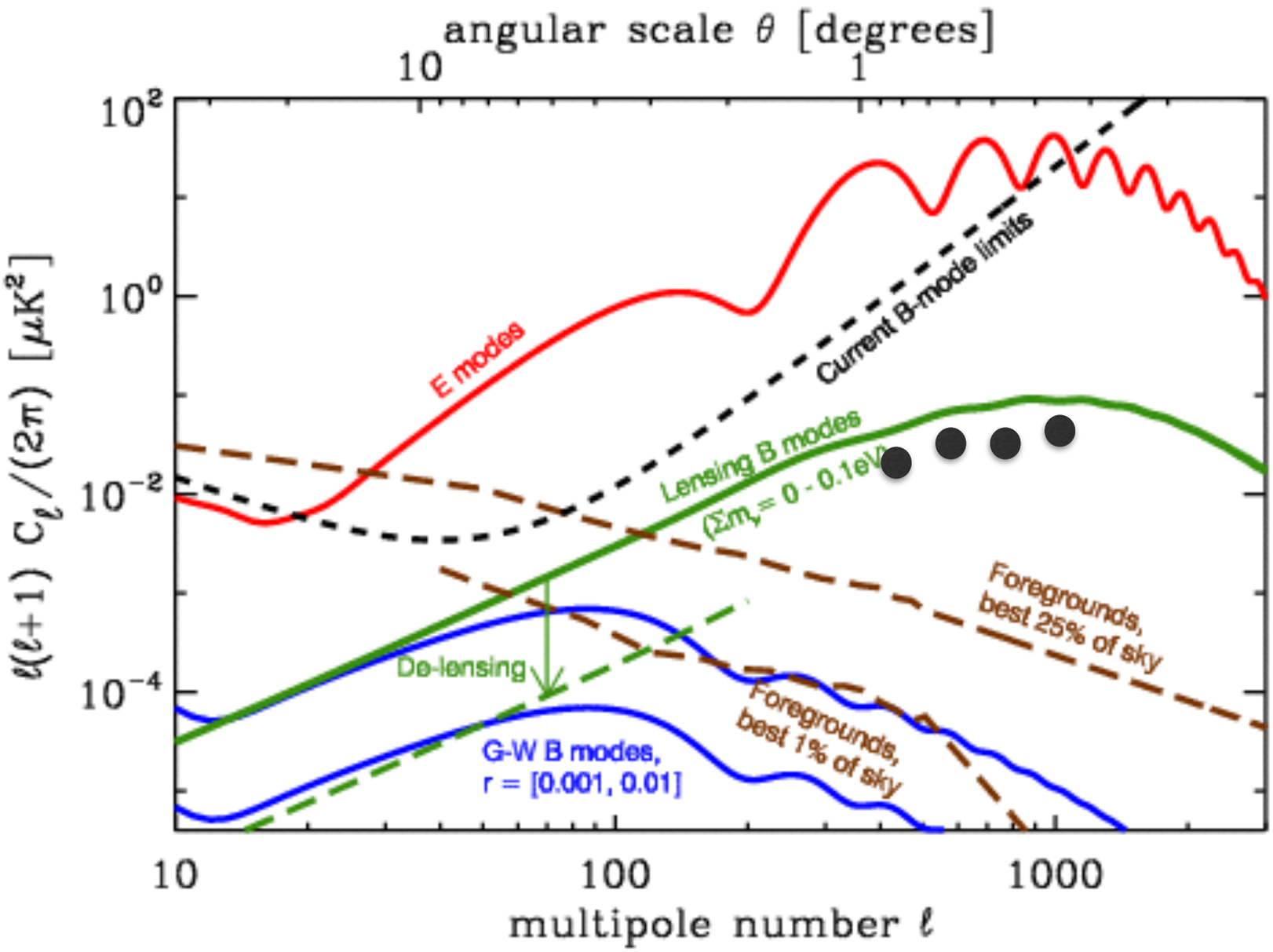
slides at:

# SIMS

Note: we have filtering, foregrounds (gaussian), CIB from model.

# DELENSING: LONG (EXCITING) WAY TO GO.

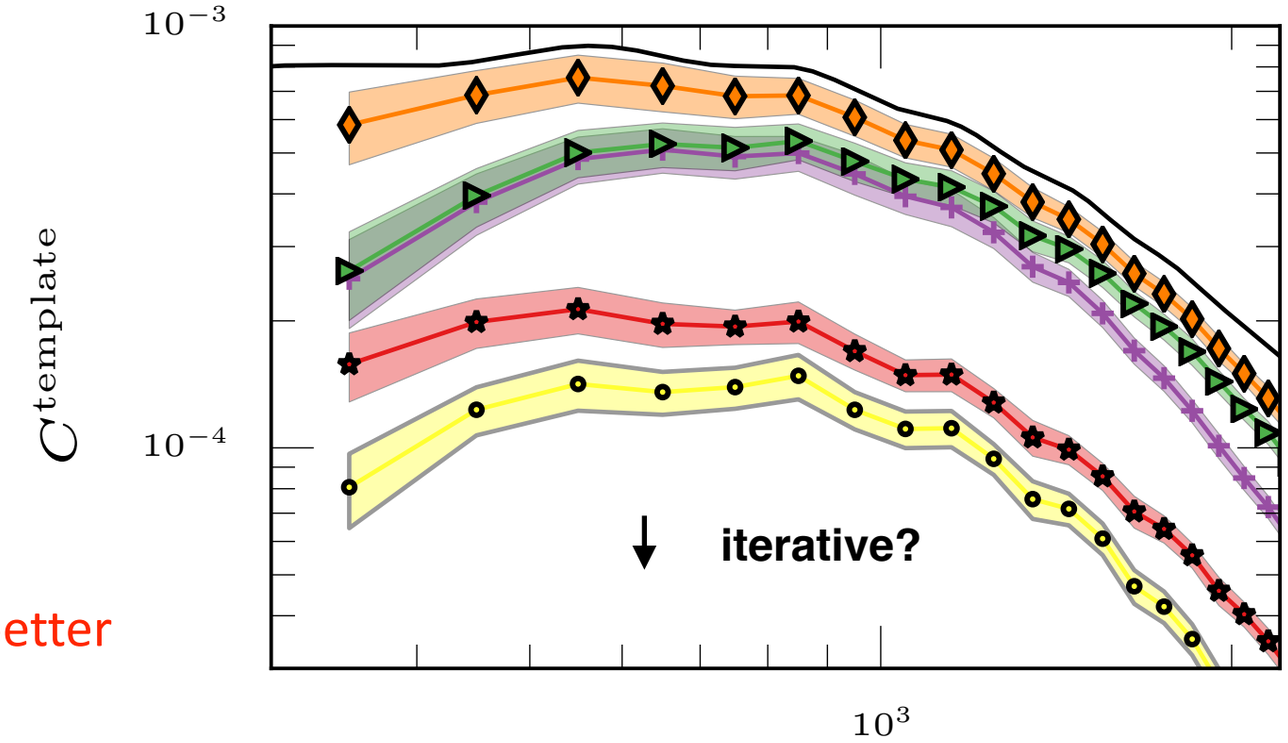



- This analysis

# DELENSING EFFICIENCY: BIG PICTURE

## B template power spectrum

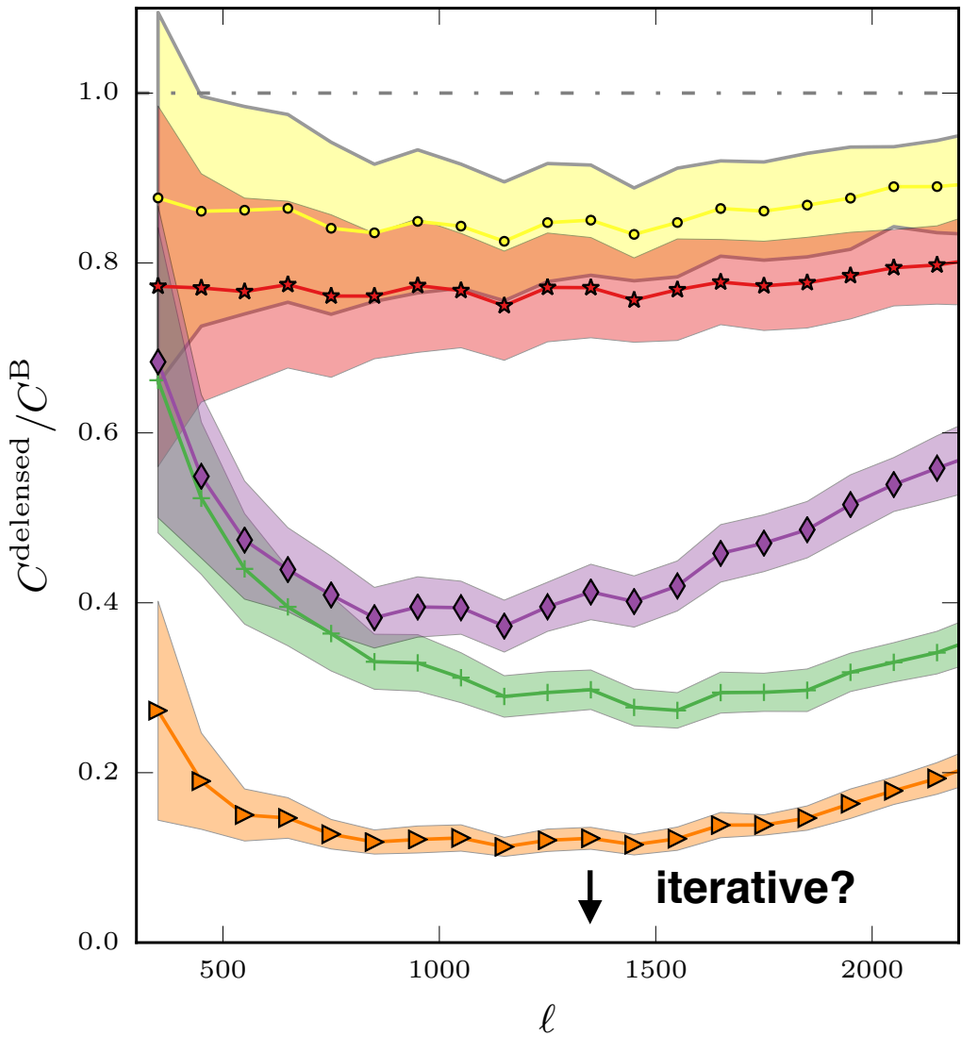
better




$E_{\rm unfiltered} - \phi_{\rm noiseless}$
$E_{\rm noiseless} - \phi_{\rm noiseless}$
BB Theory
$E_{\rm noisy} - \phi_{\rm CIB}$
$E_{\rm unfiltered} - \phi_{\rm CIB}$
$E_{\rm noisy} - \phi_{\rm noiseless}$

# DELENSING EFFICIENCY: BIG PICTURE

## Lensing Clbb residuals




$\} \bar{\phi}_{\rm CIB}$

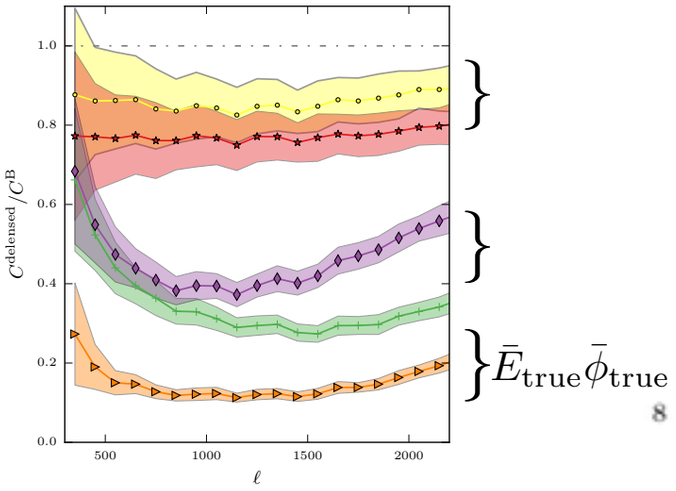
$\} \bar{\phi}_{\rm true}$

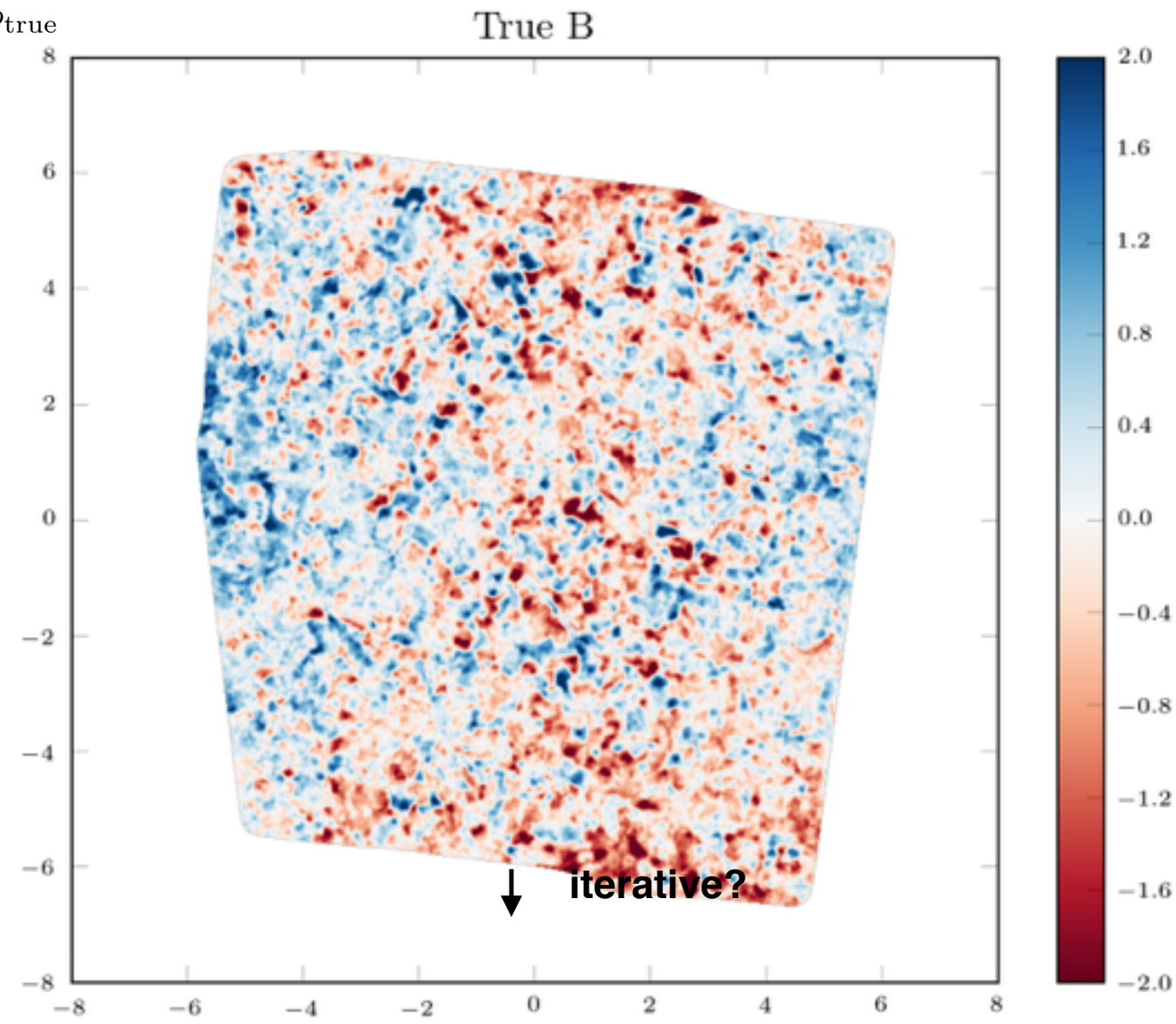
$\} \bar{E}_{\rm true}\bar{\phi}_{\rm true}$

better (less residual power)

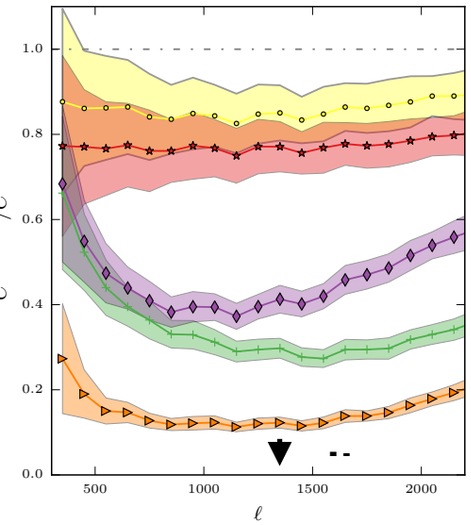
$E_{\rm unfiltered} - \phi_{\rm noiseless}$
$E_{\rm noiseless} - \phi_{\rm noiseless}$
BB Theory
$E_{\rm noisy} - \phi_{\rm CIB}$
$E_{\rm unfiltered} - \phi_{\rm CIB}$
$E_{\rm noisy} - \phi_{\rm noiseless}$

# DELENSING EFFICIENCY: MAPS



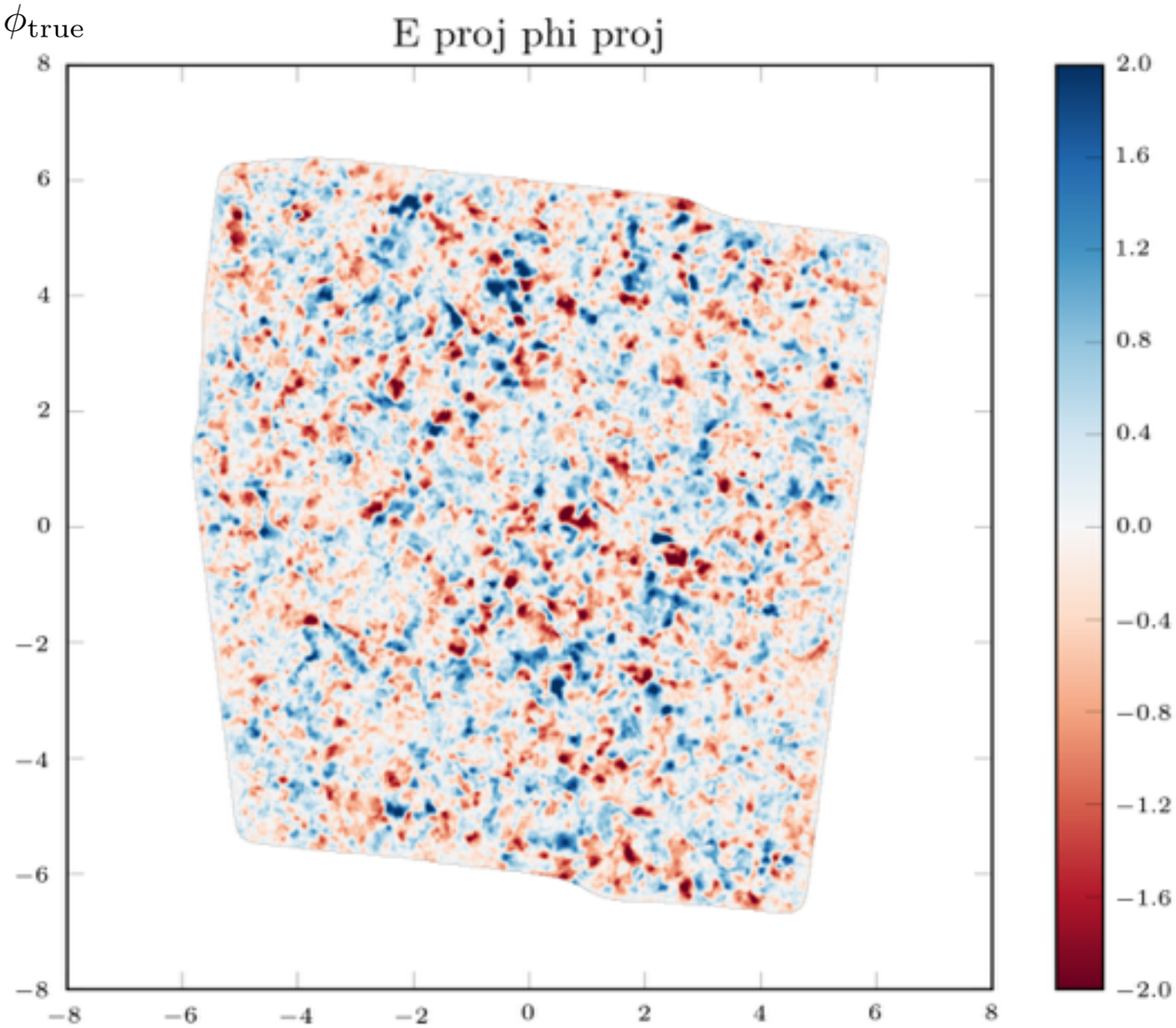



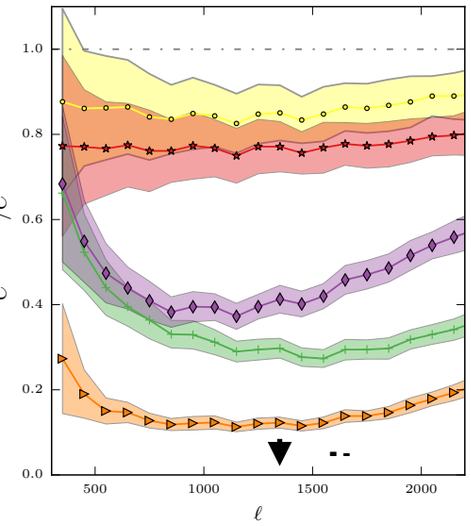
# DELENSING EFFICIENCY: PERFECT INPUT




$\} \bar{E}_{\rm true}\bar{\phi}_{\rm true}$

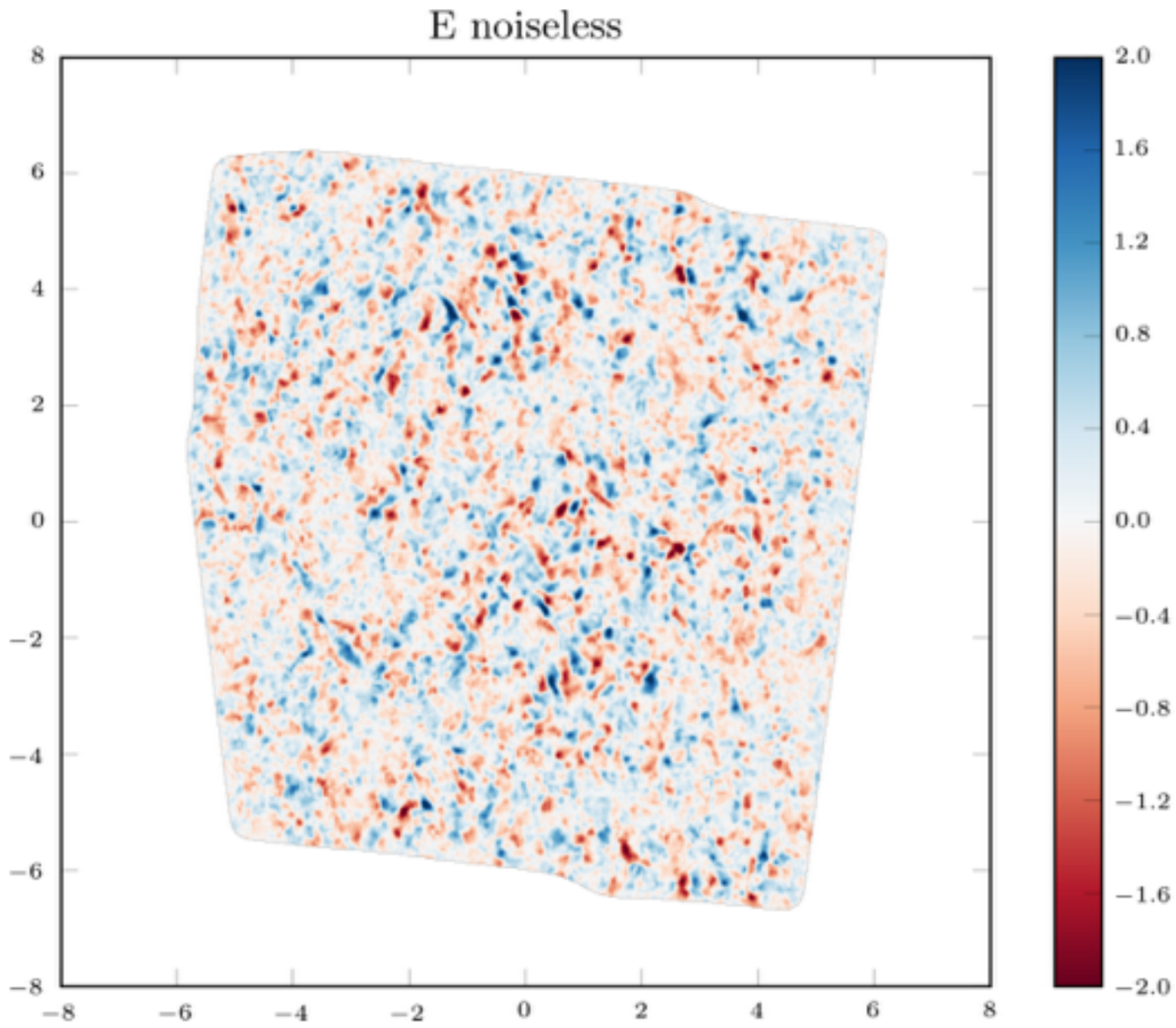
**iterative?**



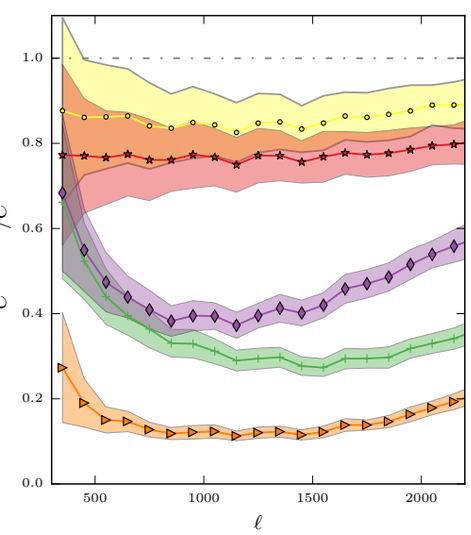



# DELENSING EFFICIENCY: NOISELESS FILTERED E

} $\bar{\phi}_{\rm true}$

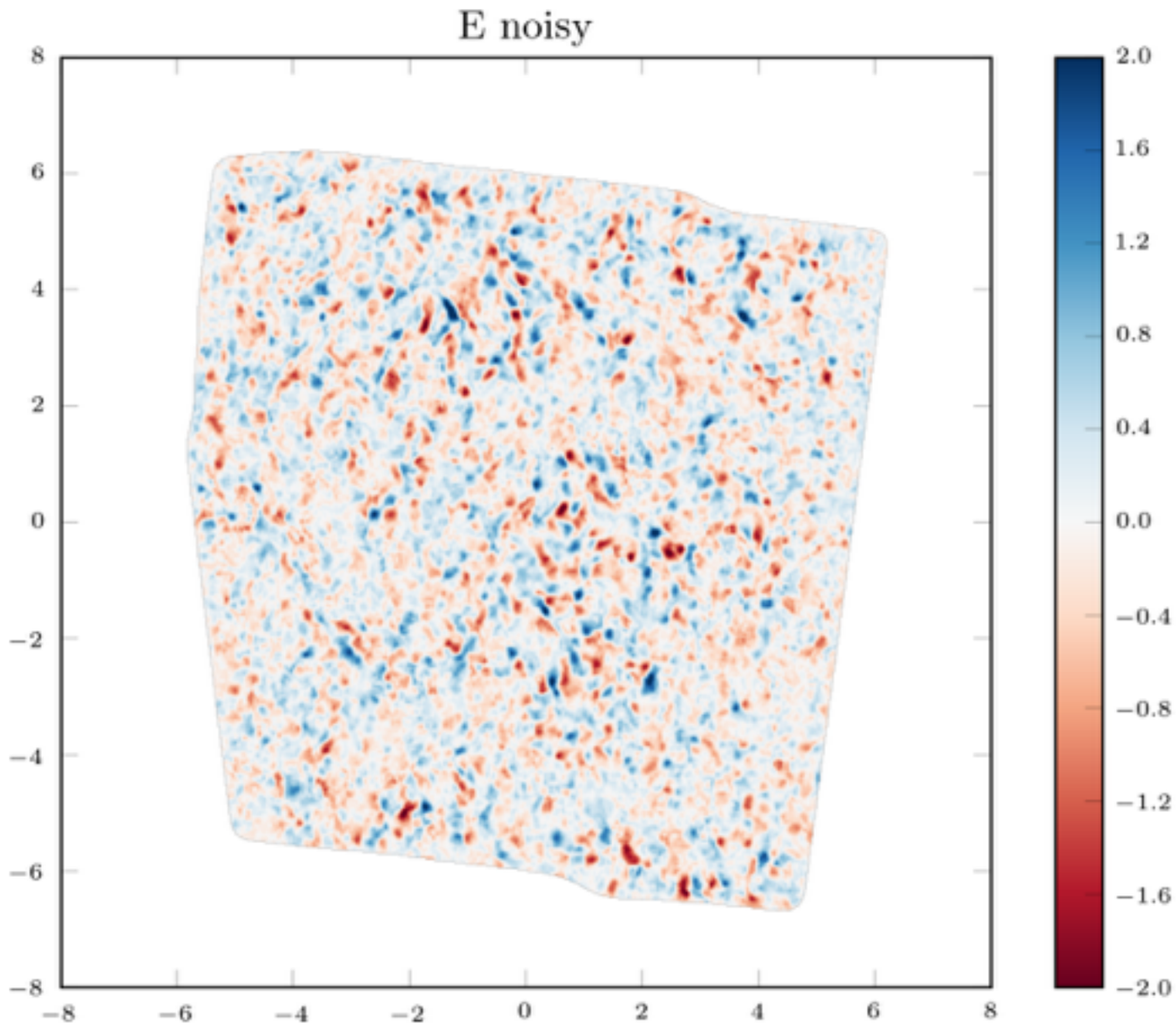


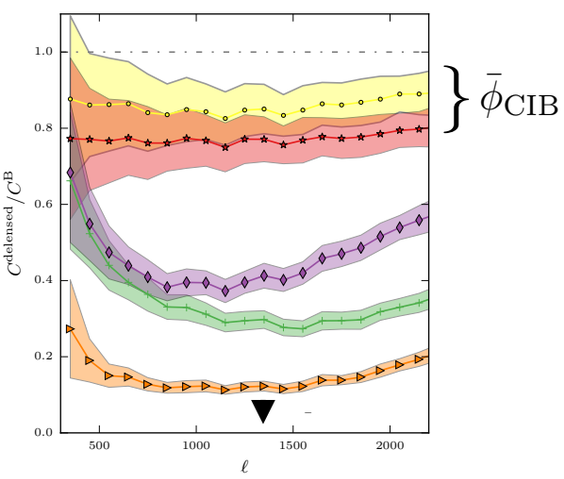
# DELENSING EFFICIENCY: NOISY FILTERED E




$\} \bar{\phi}_{\rm true}$

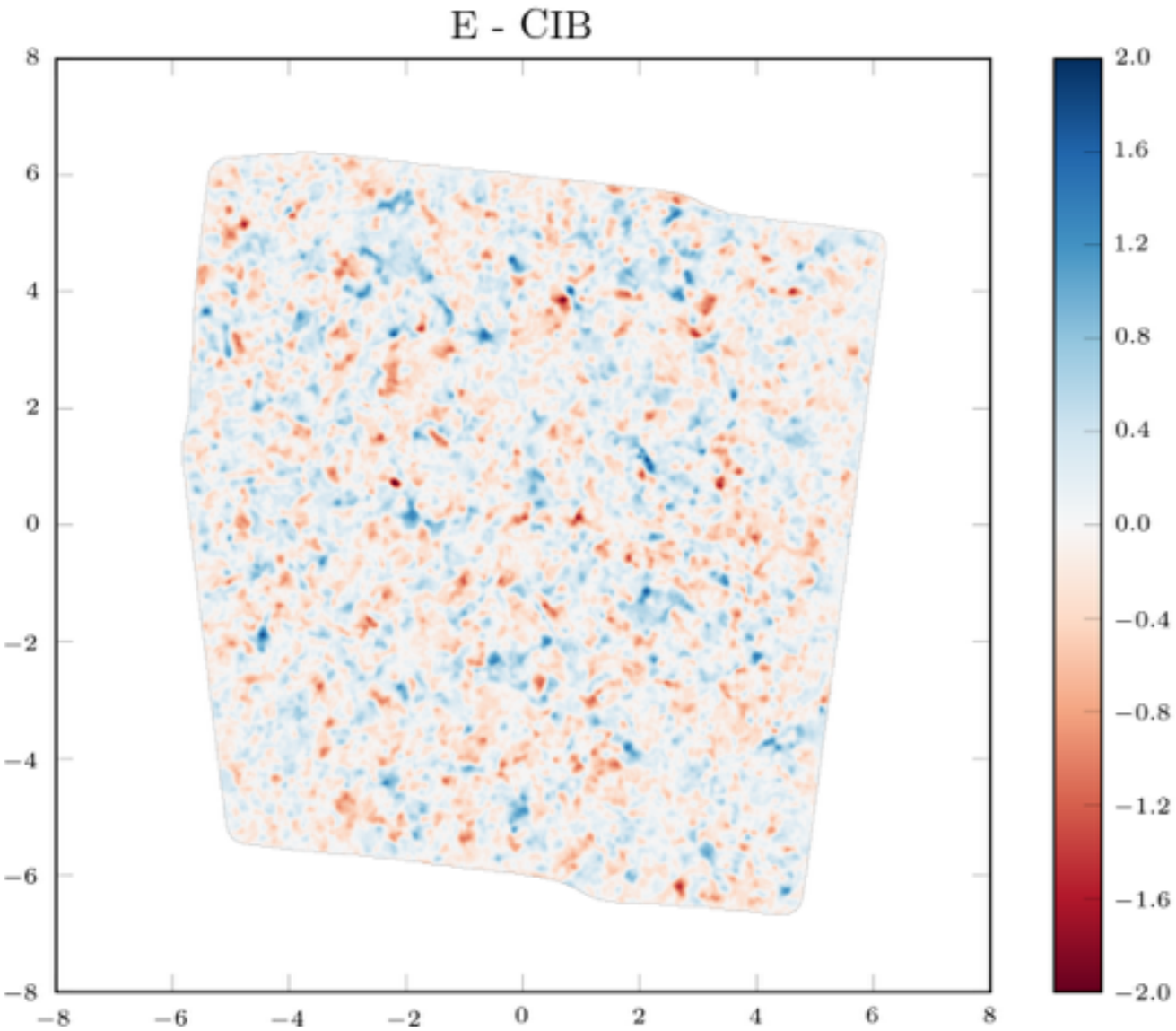
**At least for SPT at this scales. E modes are not the problem**

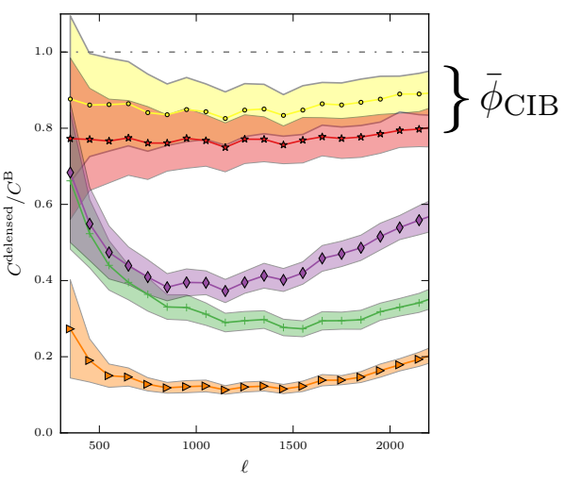




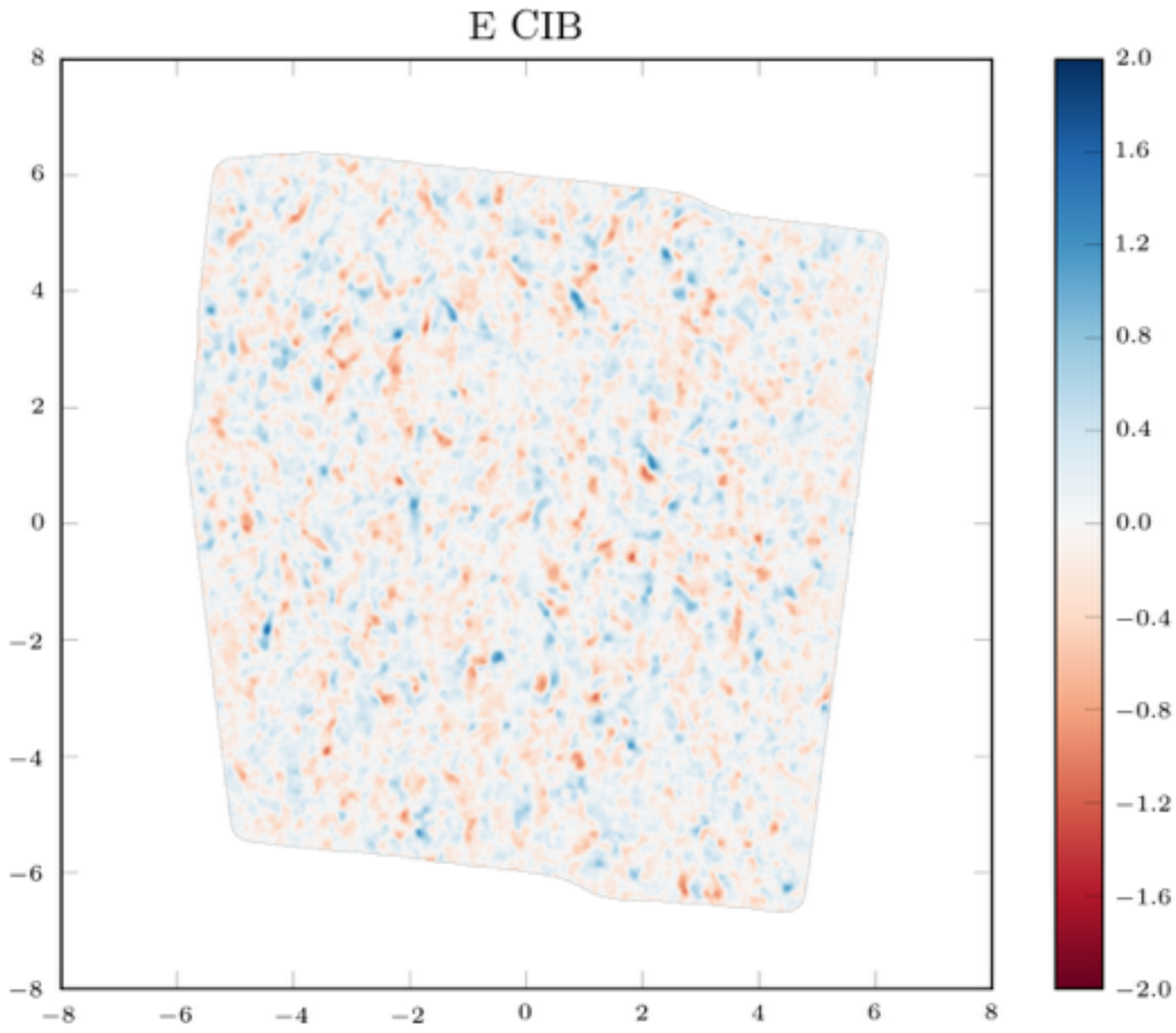

# DELENSING EFFICIENCY: MAPS

**Indeed perfect E but lensing from CIB..**




# DELENSING EFFICIENCY: MAPS



# THE CHALLENGES

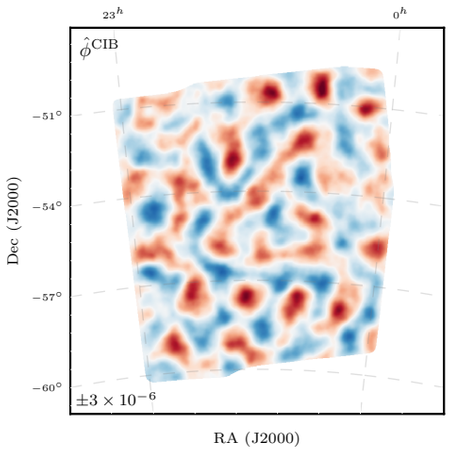
- The **B mode map** and the **B mode template** we want to subtract are coming from different analysis. They have **different filtering, missing modes, different point sources threshold**.

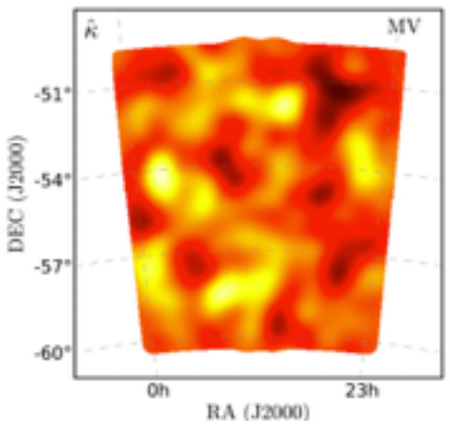
- We are **testing** the technique for the **first time** on **data**. **Using** this to improve r constraint **required** an **unprecedented control of systematics**.
- Analyze delensed data. Covariances?
- Estimate systematics contamination: dust.

# THE FUTURE

Reasonable goals by end of 2017

- On the 500deg^2 SPT combine Planck CIB and CMB lensing reconstruction.

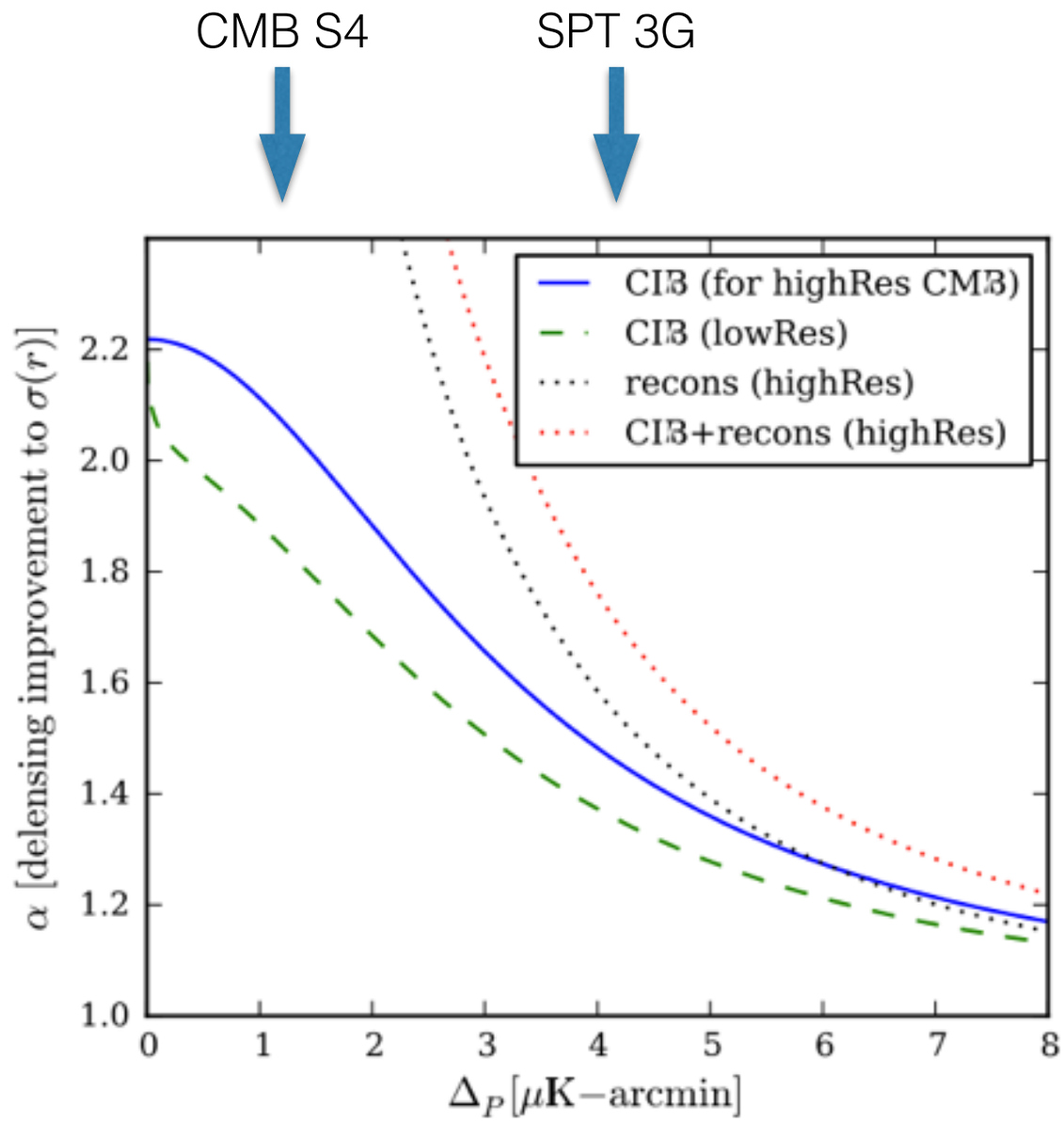



- Delens BICEP-KECK with the help of BICEP data.

Lensing Potential from CIB

v.s. CMB reconstruction




Sherwin & Schmittfull 2015

# ADVERTISEMENT: 2DX3D FORMALISM IN GALAXY SURVEYS

With Sam Passaglia 1st year

We know how to get cosmology from 2D samples

Expand in $Y_{lm}(\theta)$ Compute $\langle a_{lm} a_{l'm'} \rangle$

For 3D, we usually expand in $e^{ikx}$... but if we want to cross-correlate with 2D:

Expand in $Y_{lm}(\theta)$ AND $j_l(kr)$

Compute $\langle a_{lm} b_{l'm'}(k) \rangle$ and $\langle b_{lm}(k) b_{l'm'}(k') \rangle$

Retains diagonality in l and m

# Application: Photo-z Galaxies and Clusters

Photometric surveys produce tomographic galaxy bins

Each bin essentially a 2D sample

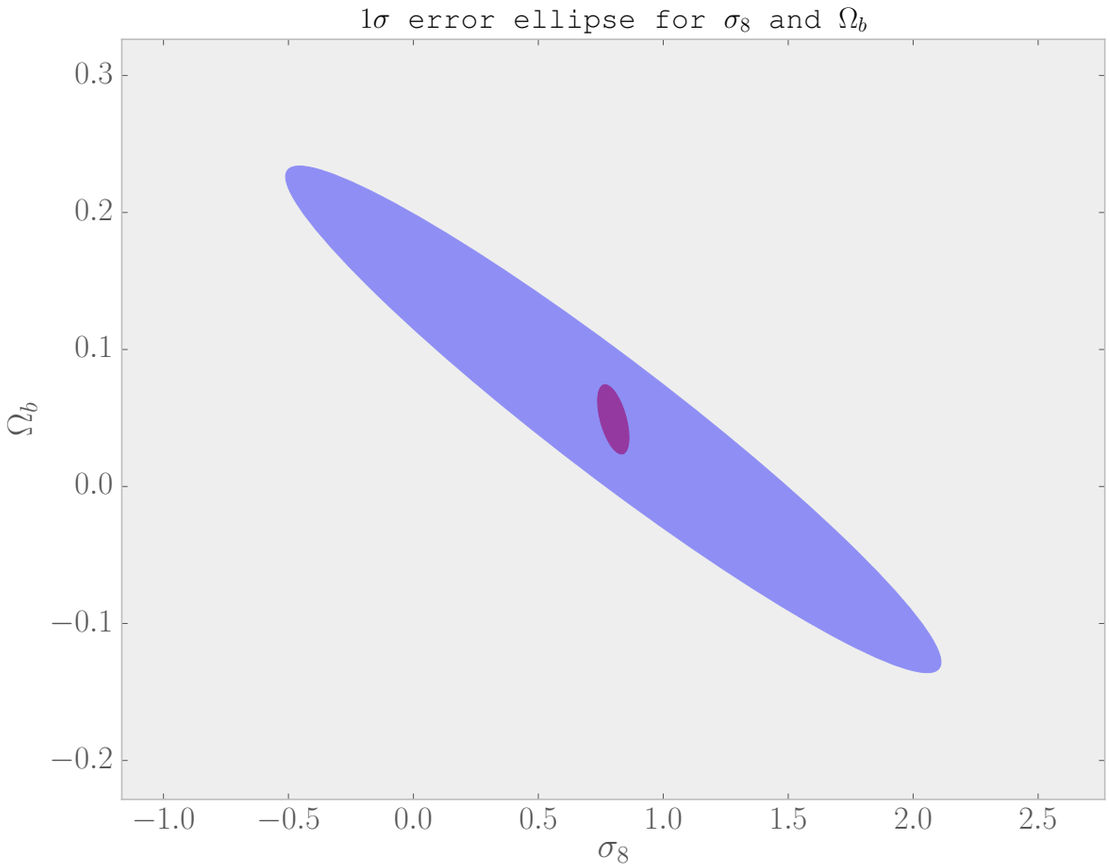
We can use our framework to make optimal use of overlapping 3D samples

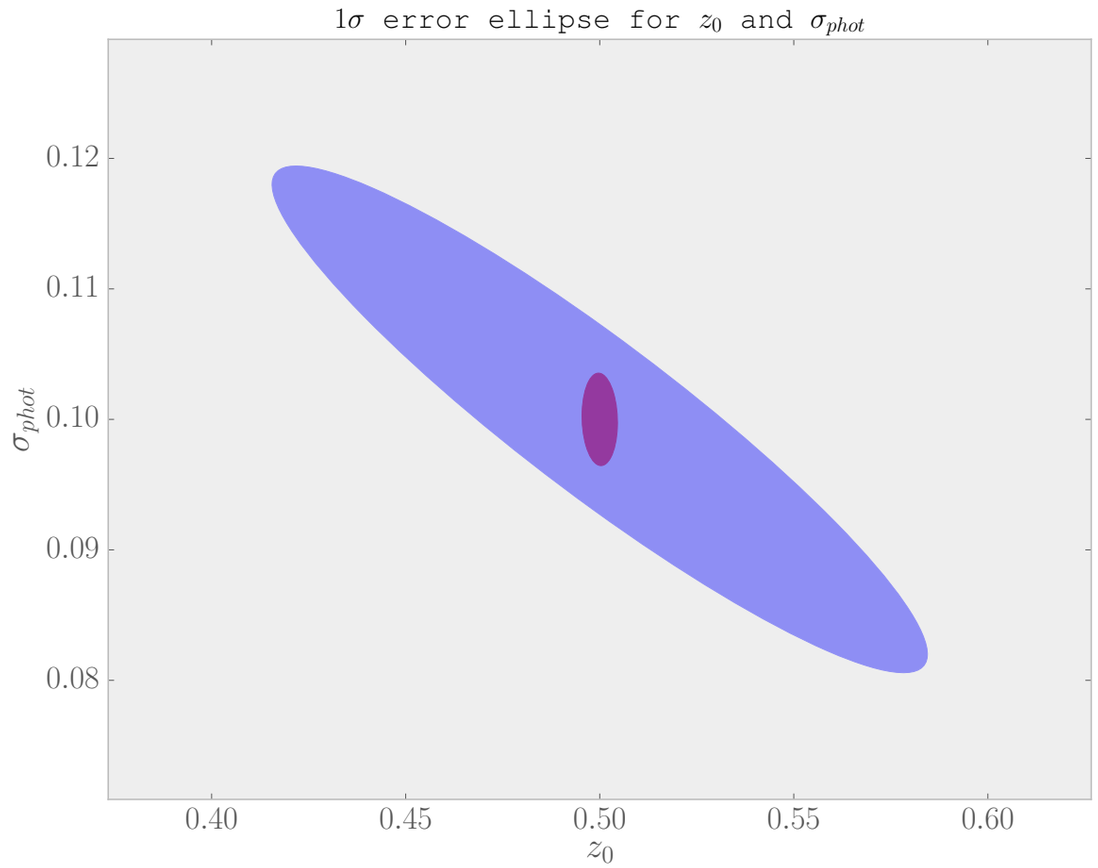
Ex: redMapper Clusters, Spectroscopic galaxies

For DES clustering analyses, clusters are lumped with galaxies

What if we treat clusters as a true 3D sample?

# Results: Fisher Analysis for a DES-like survey



Kavli Institute
for Cosmological Physics
at The University of Chicago

# CONCLUSION

- Delensing is crucial and it is working. Results in agreement with sims. Right now all the collaborations and the CMB Stage 4 community are working hard.

- Happy to chat about:

- 2Dx3D formalism
- dark matter perturbation theory
- LIGO early localization of electromagnetic counterparts,
- modular software for parameters constraints,
- CMB Stage 4 and galaxies forecast,
- optimal map reconstruction: ISW
- effect of long wave modes on deep CMB experiments.

Alessandro Manzotti, KICP Chicago

slides at: