CMB B-MODES ARE A KEY PROBE OF THE EARLY UNIVERSE

"Turning" E mode into B mode

CMB photons
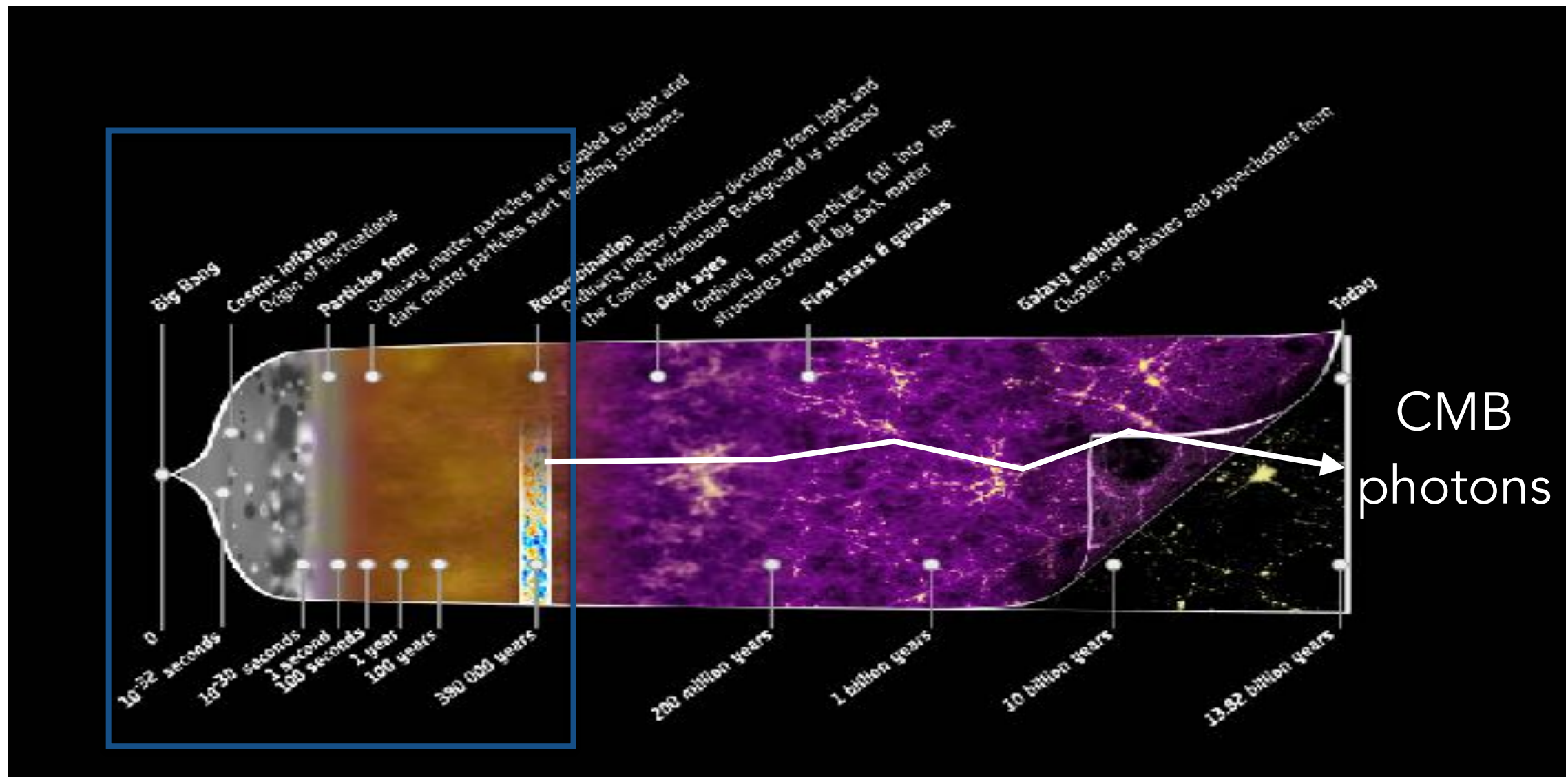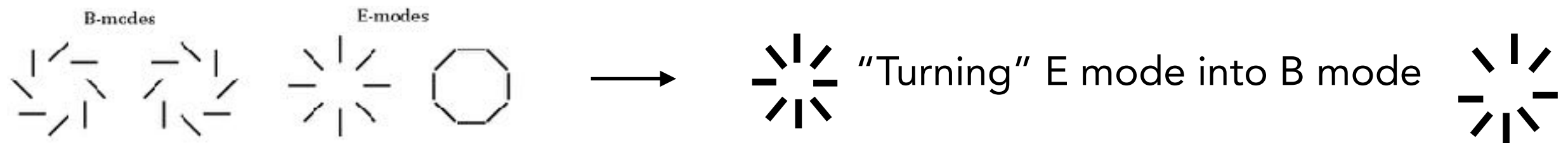
Inflation signature imprinted in CMB polarization B-modes

Lensing is now a source of confusion that mixes primordial E-B modes

Time (distance light travels)

B-MODE LENSING IS AS BIG AS THE INFLATIONARY SIGNAL

Angular scale

Primordial r=0.1
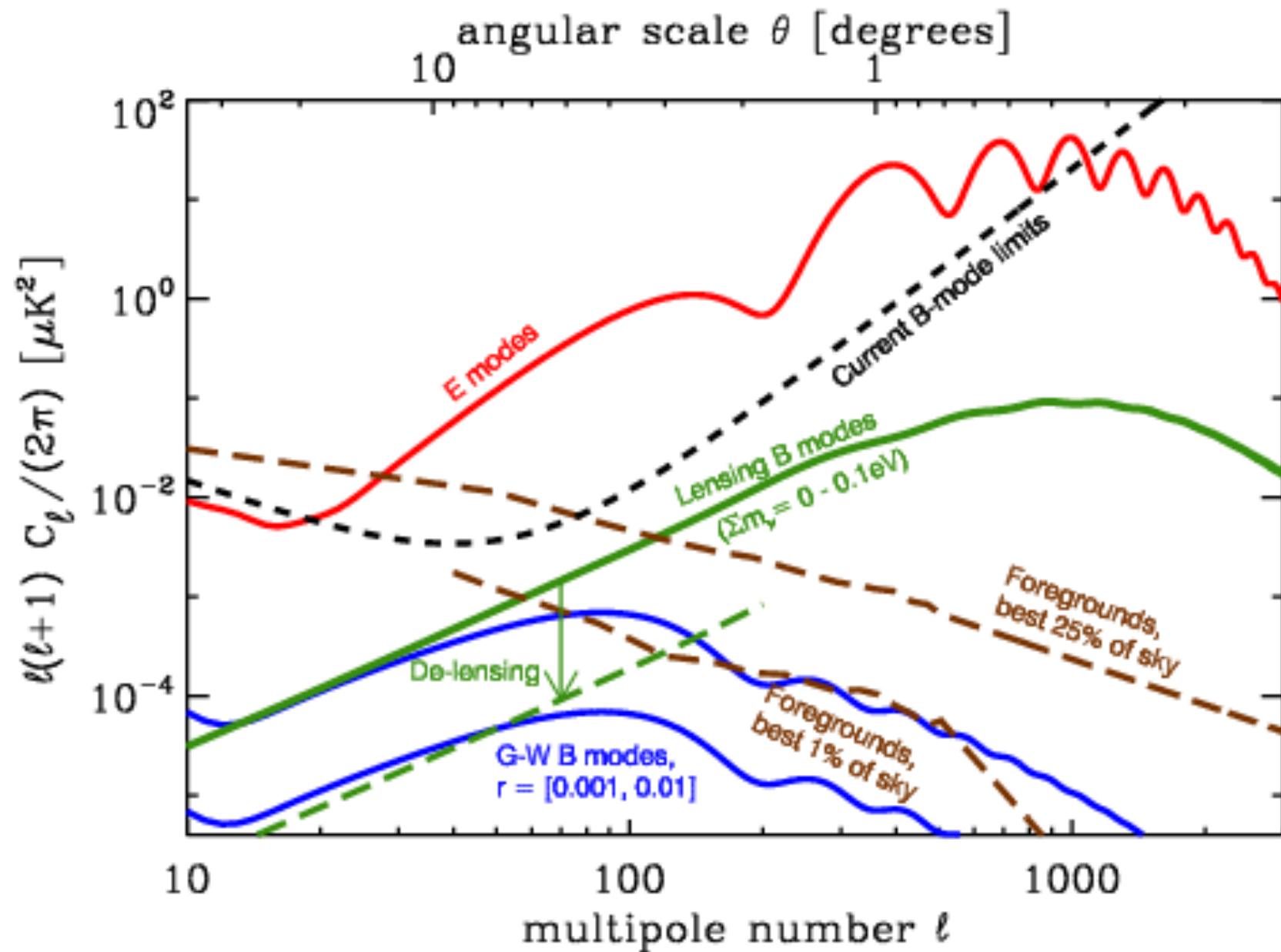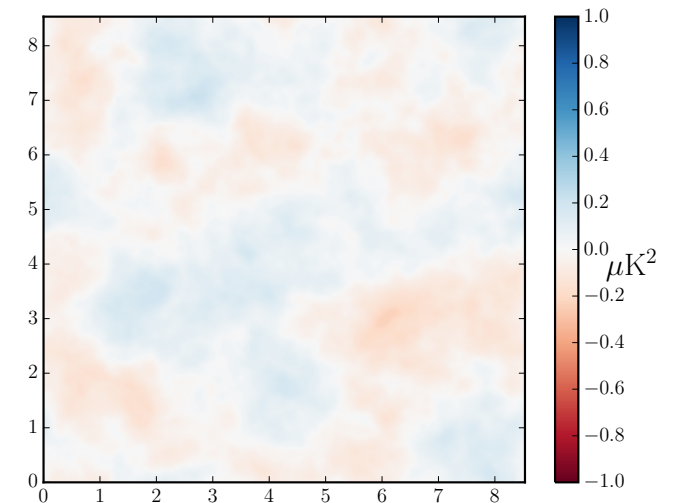

Lensing
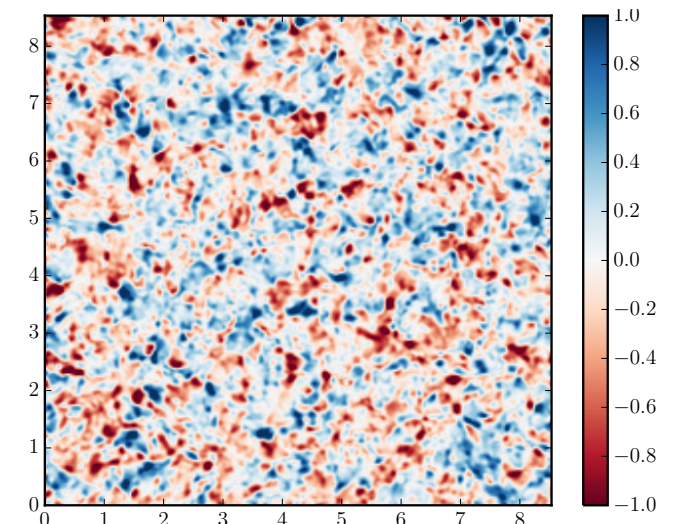
P
o
w
e
r

This significantly degrade constraints on r
(factor of 3-4 for CMB S4)

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THE PATH TO THE EARLY UNIVERSE: IMPROVING INSTRUMENT, MEASURING FOREGROUNDS AND DELENS

Instrumental improvements:

Reducing instrumental noise (more detectors)

1/f noise, atmosphere, half wave plates

Astrophysical foregrounds

Component separation

Multifrequency (space?)

Delensing

This Talk. And (hopefully) your favorite.

Do not miss Marius and Anthony's delensing talks!!

DELENSING IS CRUCIAL TO LEARN ABOUT INFLATION BEFORE 2016, NEVER APPLIED ON DATA.

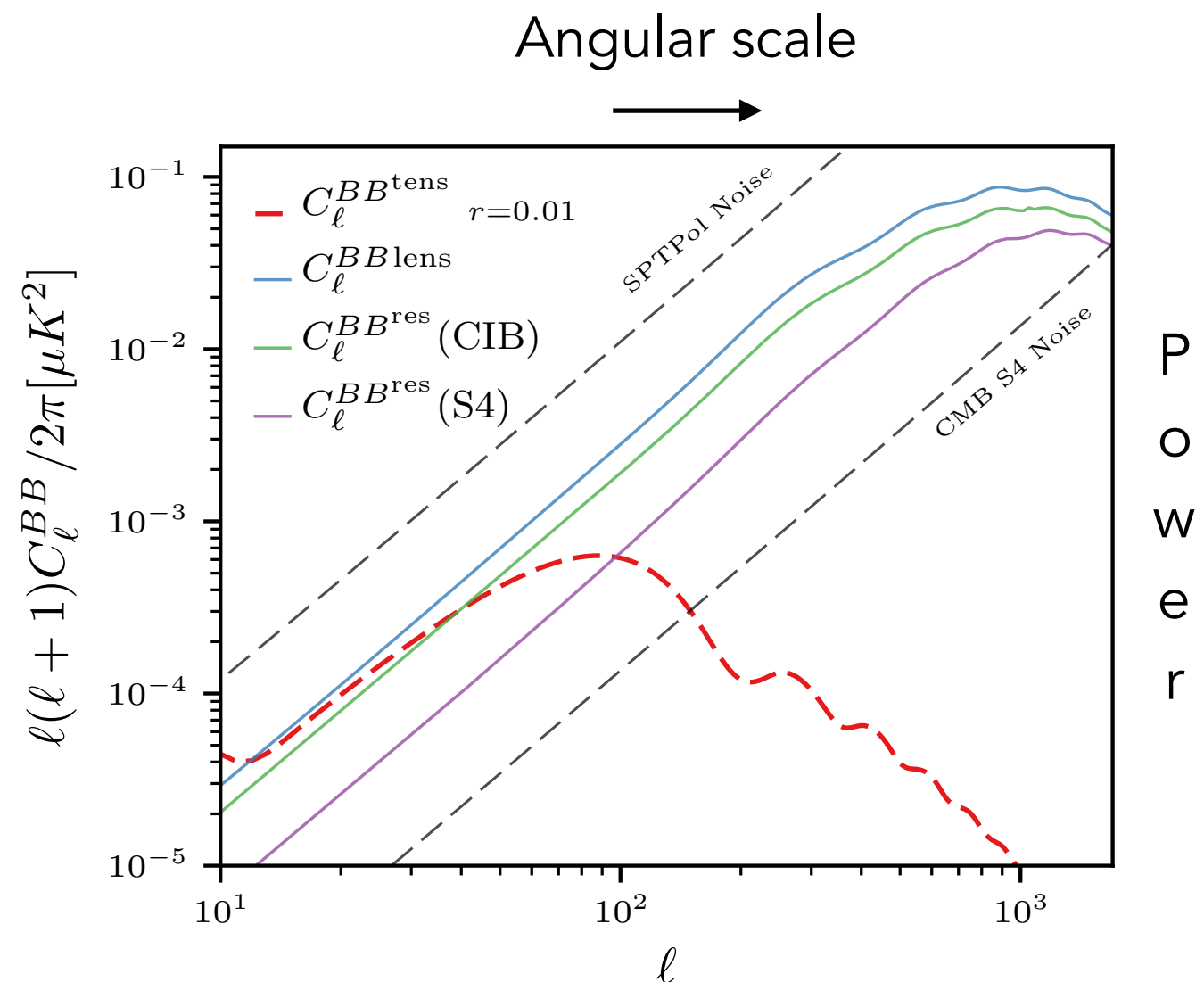# WE NEED TO REMOVE THE LENSING COMPONENT (THE VARIANCE)

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

Angular scale

- It can be seen as a white noise component at ~5 uK-arcmin.

- Not cleanable with multi band approach.

- Well modeled, but cosmic variance would be a problem

Legend:
- $C_\ell^{BB \, \text{tens}}$ $r=0.01$
- $C_\ell^{BB \, \text{lens}}$
- $C_\ell^{BB \, \text{res}}$ (CIB)
- $C_\ell^{BB \, \text{res}}$ (S4)

SPTPol Noise

CMB S4 Noise

Power

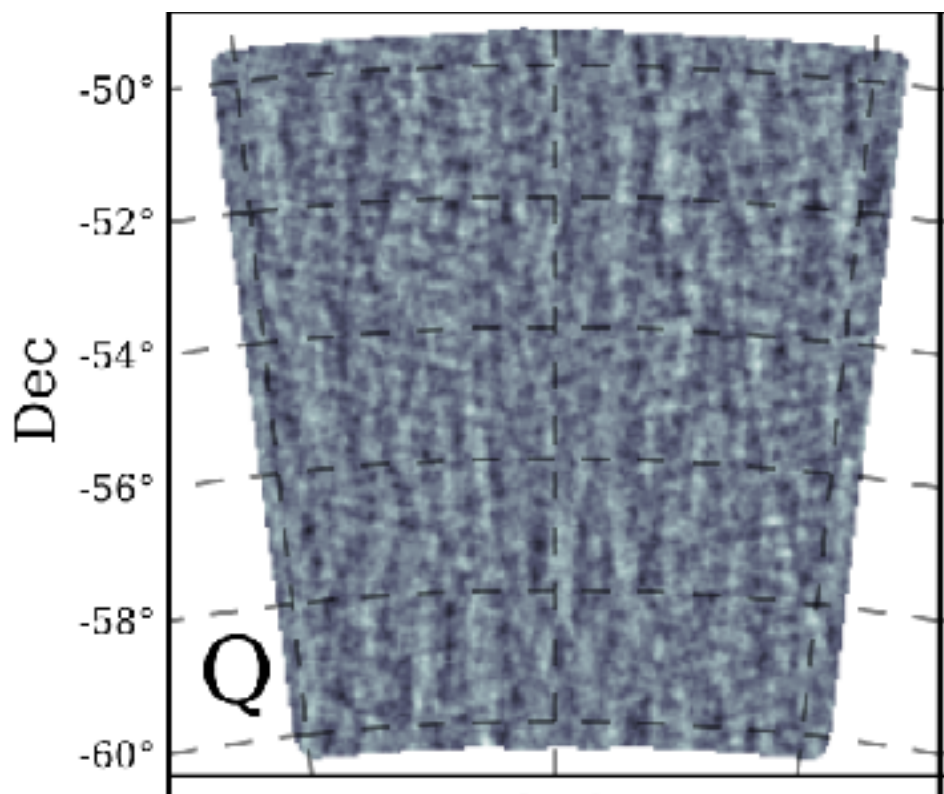$\ell(\ell+1)C_\ell^{BB}/2\pi [\mu K^2]$

ℓ

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WHAT CAN WE DO? USE 2 INGREDIENTS

Not an average, the **actual map** on the sky

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

Q-U maps

What is lensed

$\times$

?

Lensing potential map
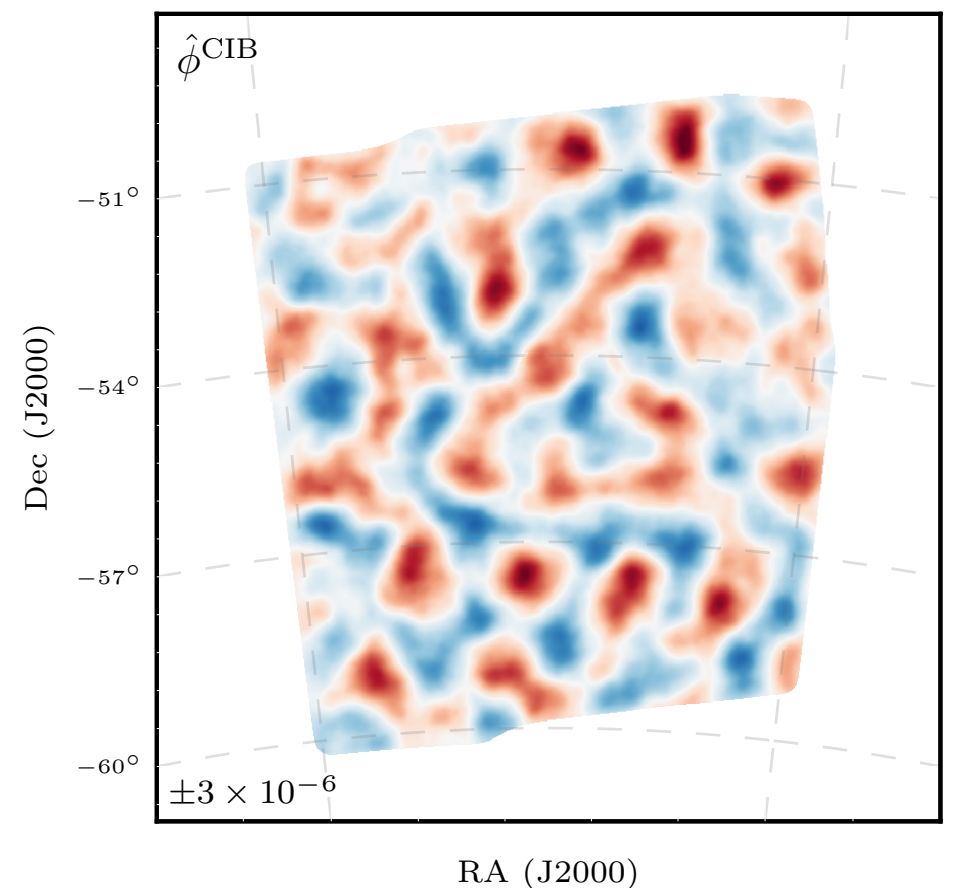
What is lensing or the lenses

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DELENSING SPTPOL DATA

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SPTPOL DONE —> SPT3G ON ITS WAY!

The South Pole Telescope: 10-meter primary dish, observe the CMB with arcminute resolution
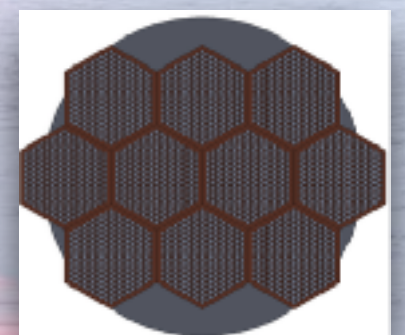
SPT-SZ (2007)

960 detectors 95,150,220 GHz

SPT-Pol (2012-2017)

1600 detectors 95,150 + Polarization

SPT-3G (20017)

~16000 detectors 95,150,220 GHz +Polarization

More on SPTPol from J Henning and SPT3G from T. Natoli

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WE DECIDED TO DELENS B-MODES USING THE SPT DATA

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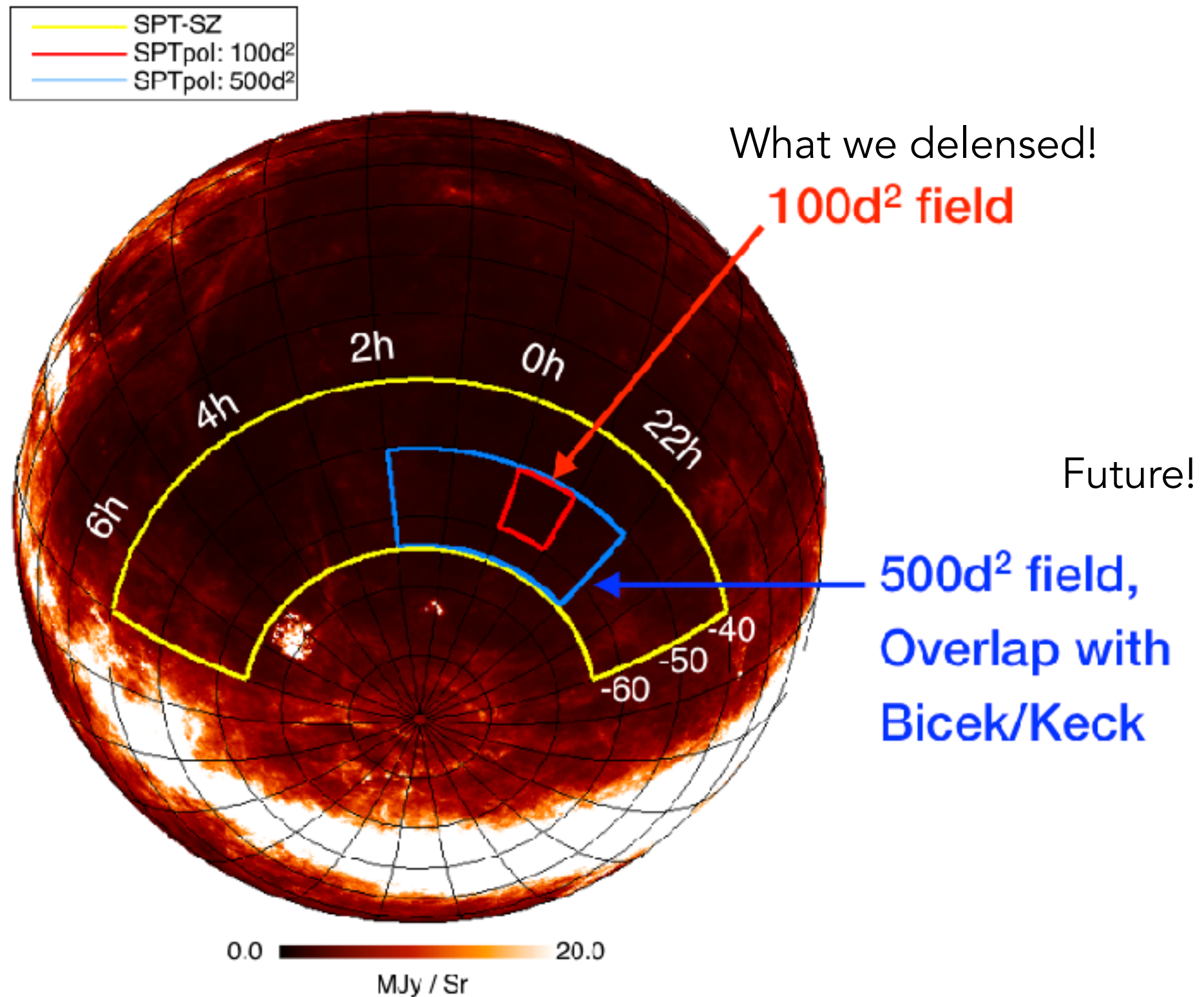
100D PATCH: A RICH DATASET

- **CIB** map: we use **Herschel** 500μm map.
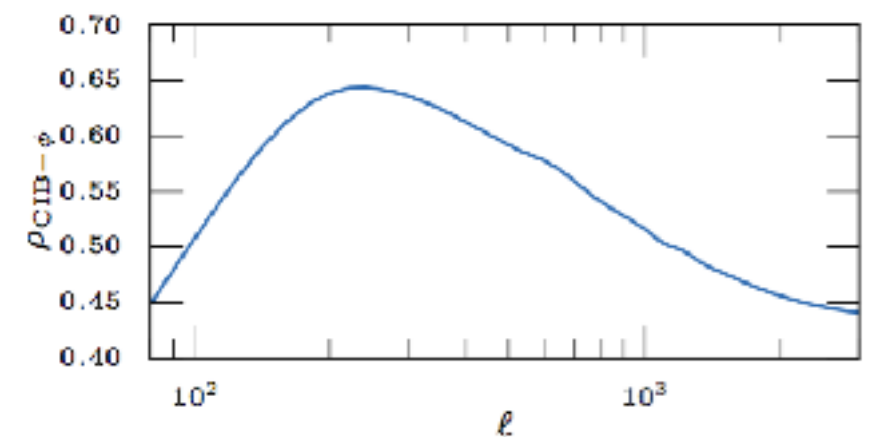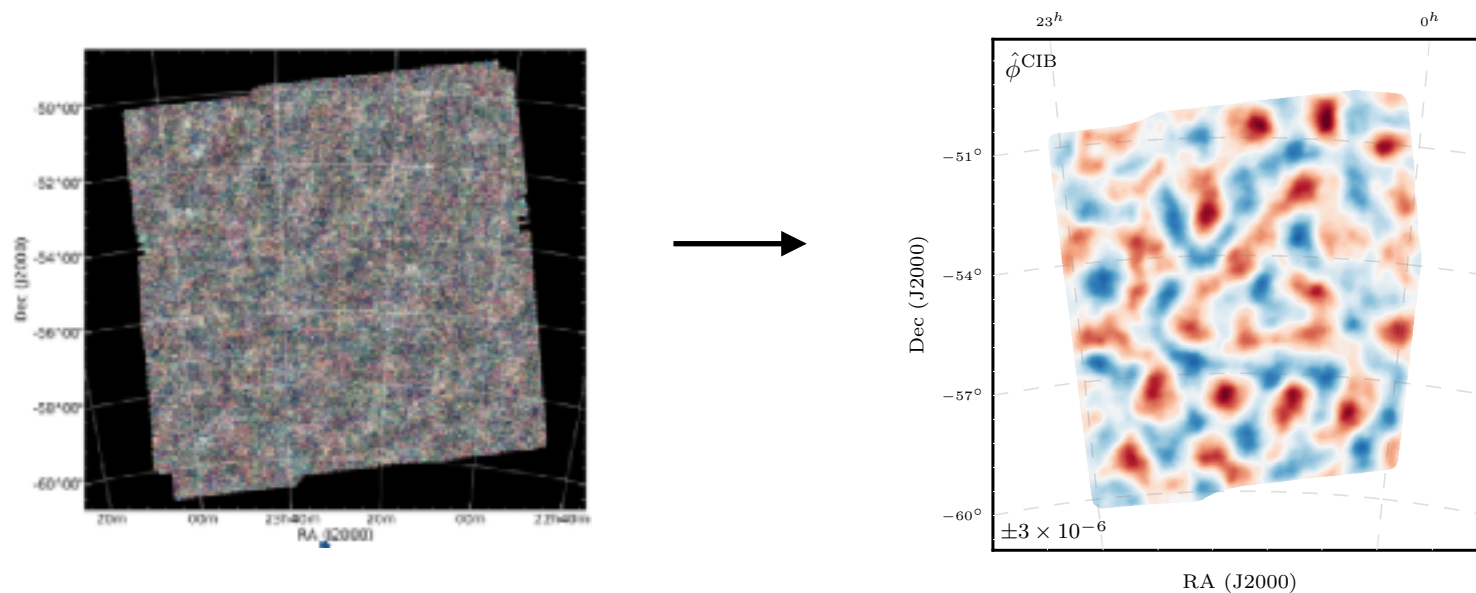
Assumed CIB-φ correlation model

- E mode (Crites, SPT 2015), B mode (Keisler, SPT 2015)

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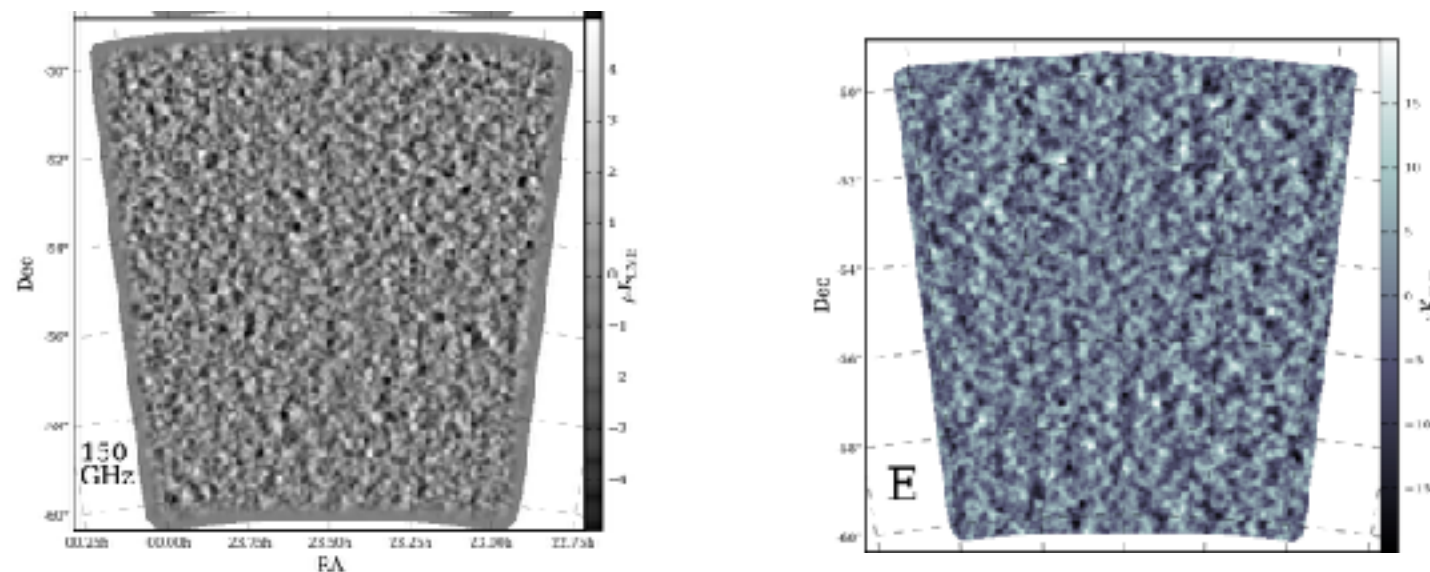
WHAT CAN WE DO? BUILD A TEMPLATE AND REMOVE!

B-mode data= signal(?) + lensing+noise   B-mode template $E \otimes \phi = B_{lens}$

$$\left(\quad - \quad \right)^2$$
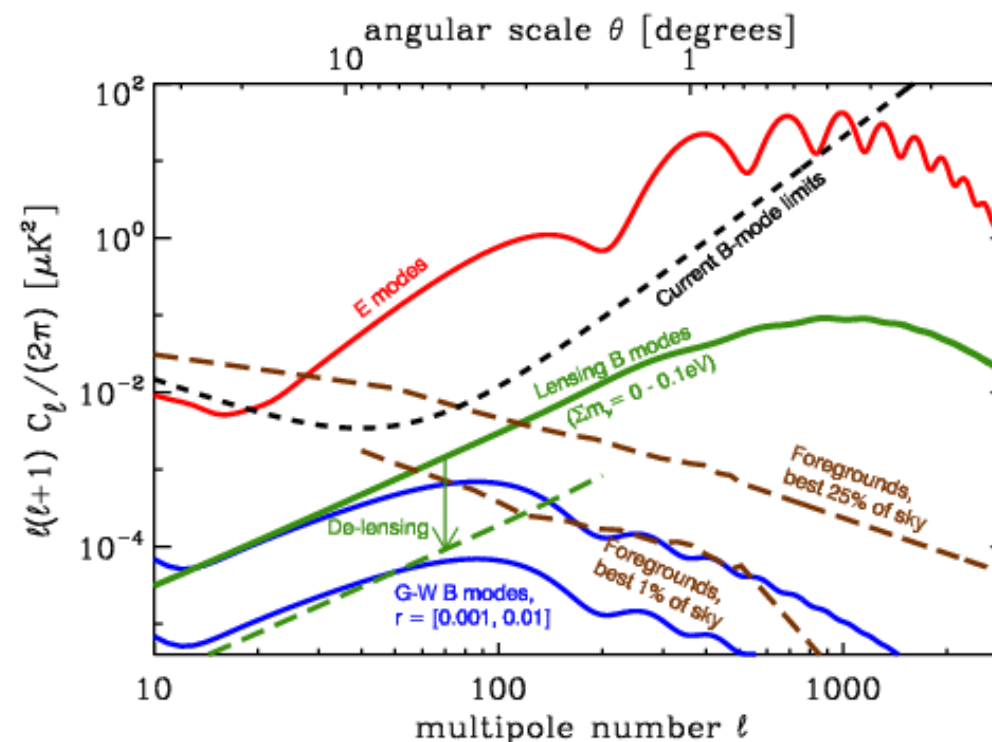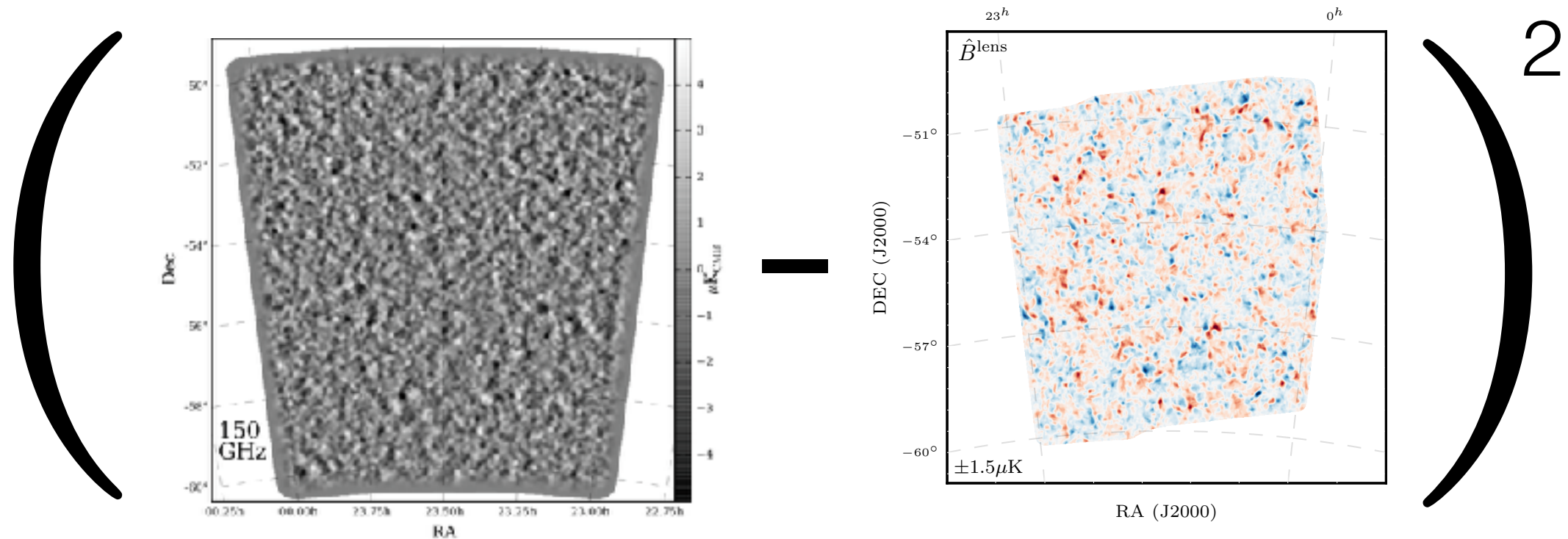
Perfect to test the technique: everything wrong will show up!

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SPT DELENSING: THE UN-DELENSED BAND POWERS

Combined

Nominal Analysis

Axis label (y): $\ell\, C_\ell^{BB}\ [10^{-3}\,\mu\mathrm{K}^2]$

Axis label (x): ℓ

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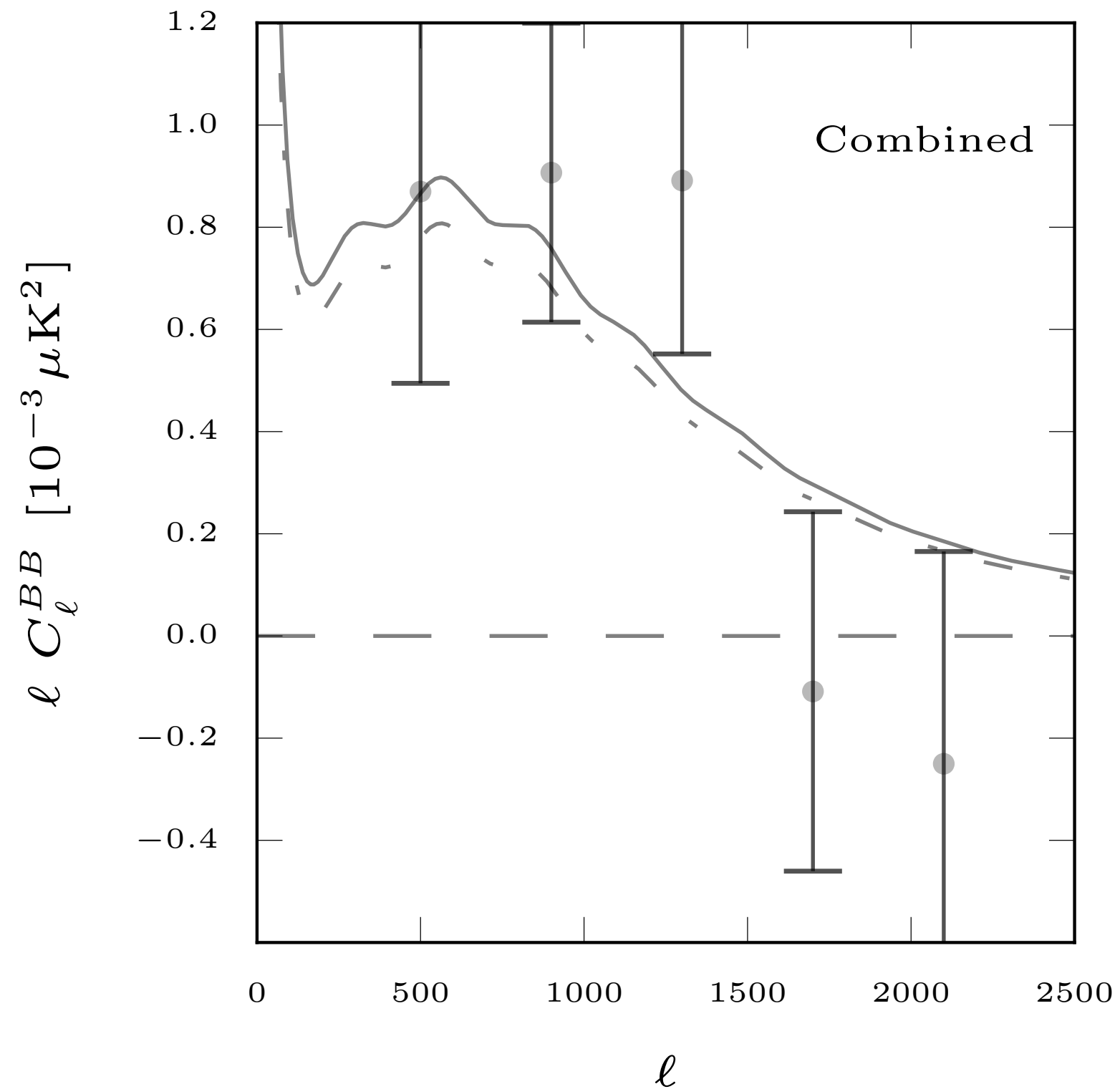
SPT DELENSING: FIRST DELENSED DATA B-MODE SPECTRUM.

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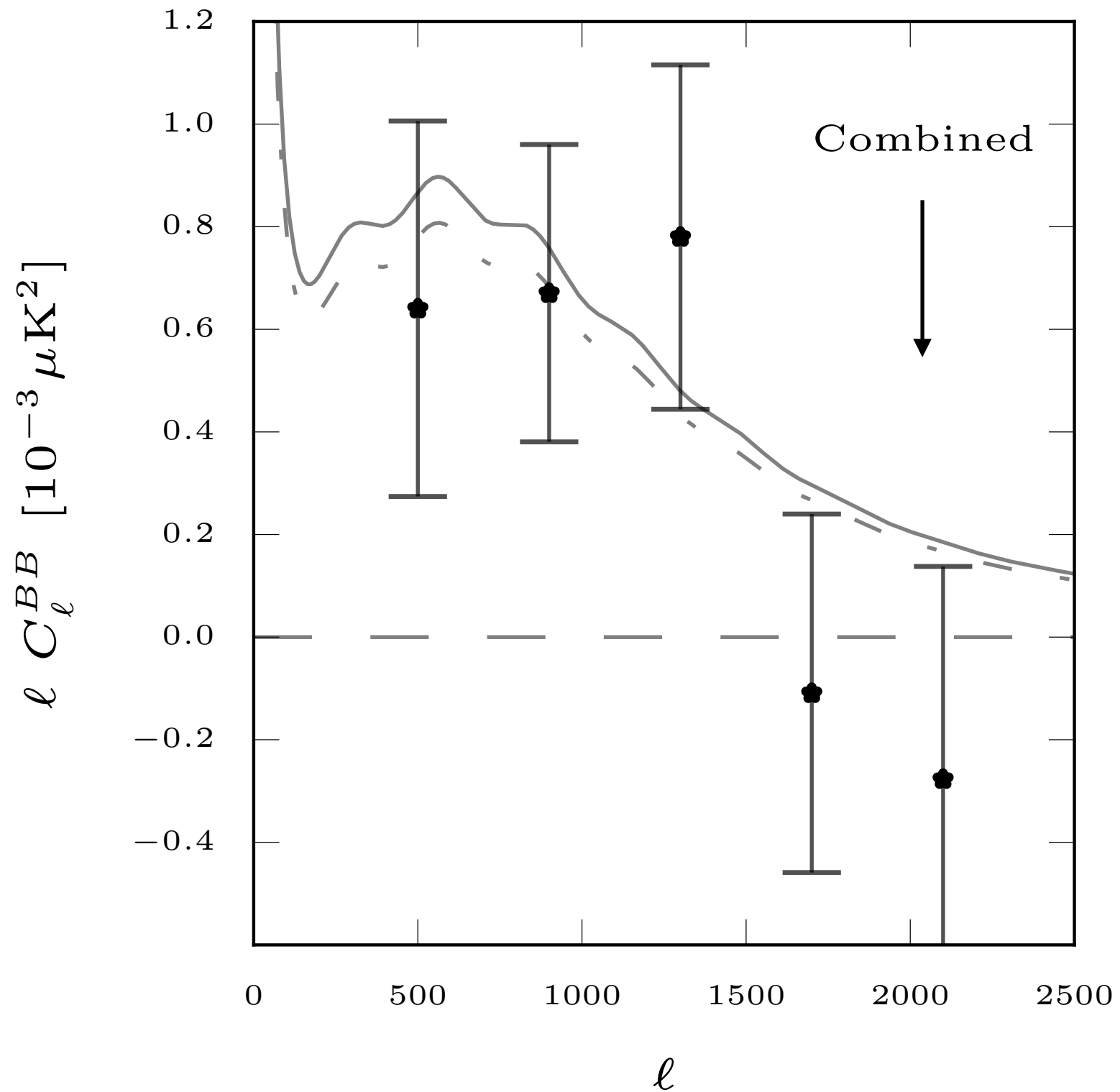
SPT DELENSING: WE REMOVE 28% OF THE POWER

Original Bandpowers

Combined

$A_{\text{lens}} = 1.06 \pm 0.29$

$A_{\text{lens}} = 0.76 \pm 0.28$

Delensed
Bandpowers
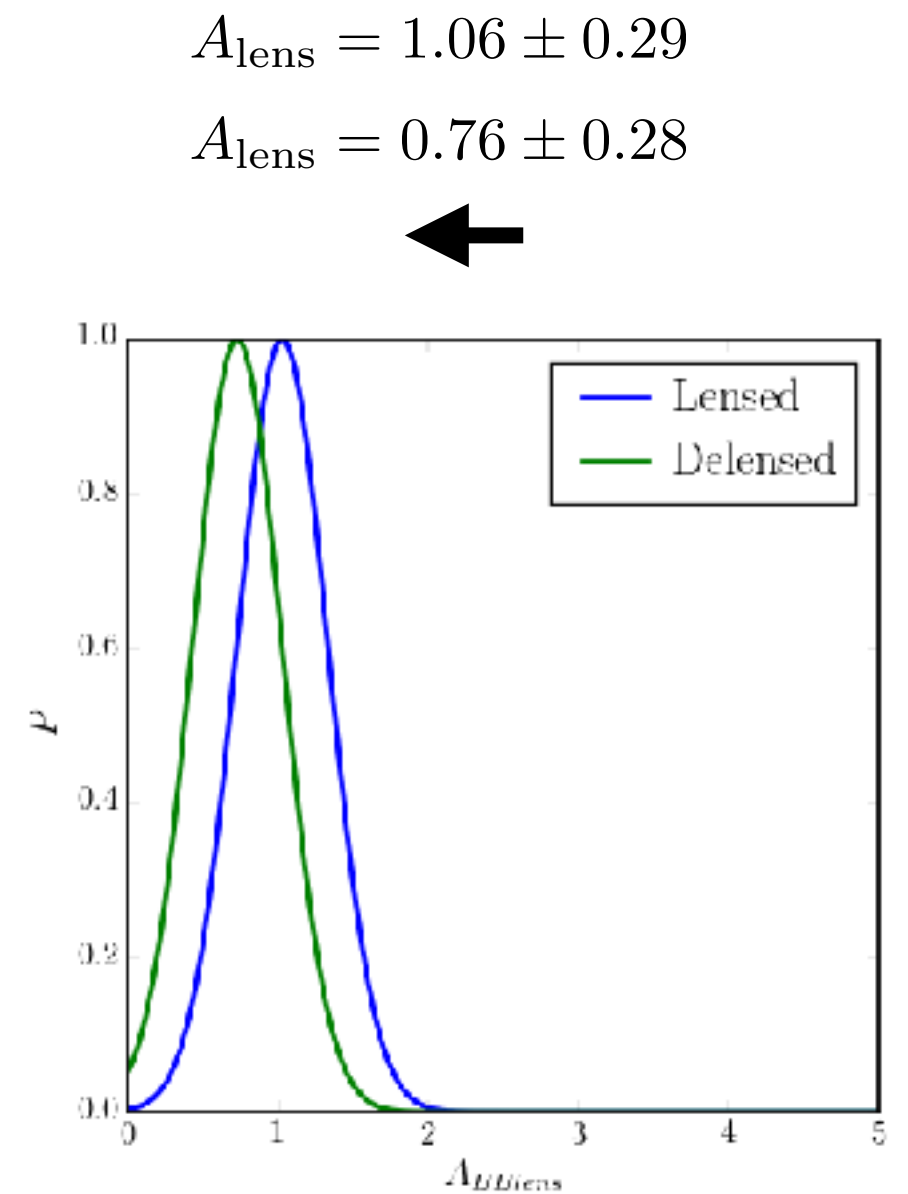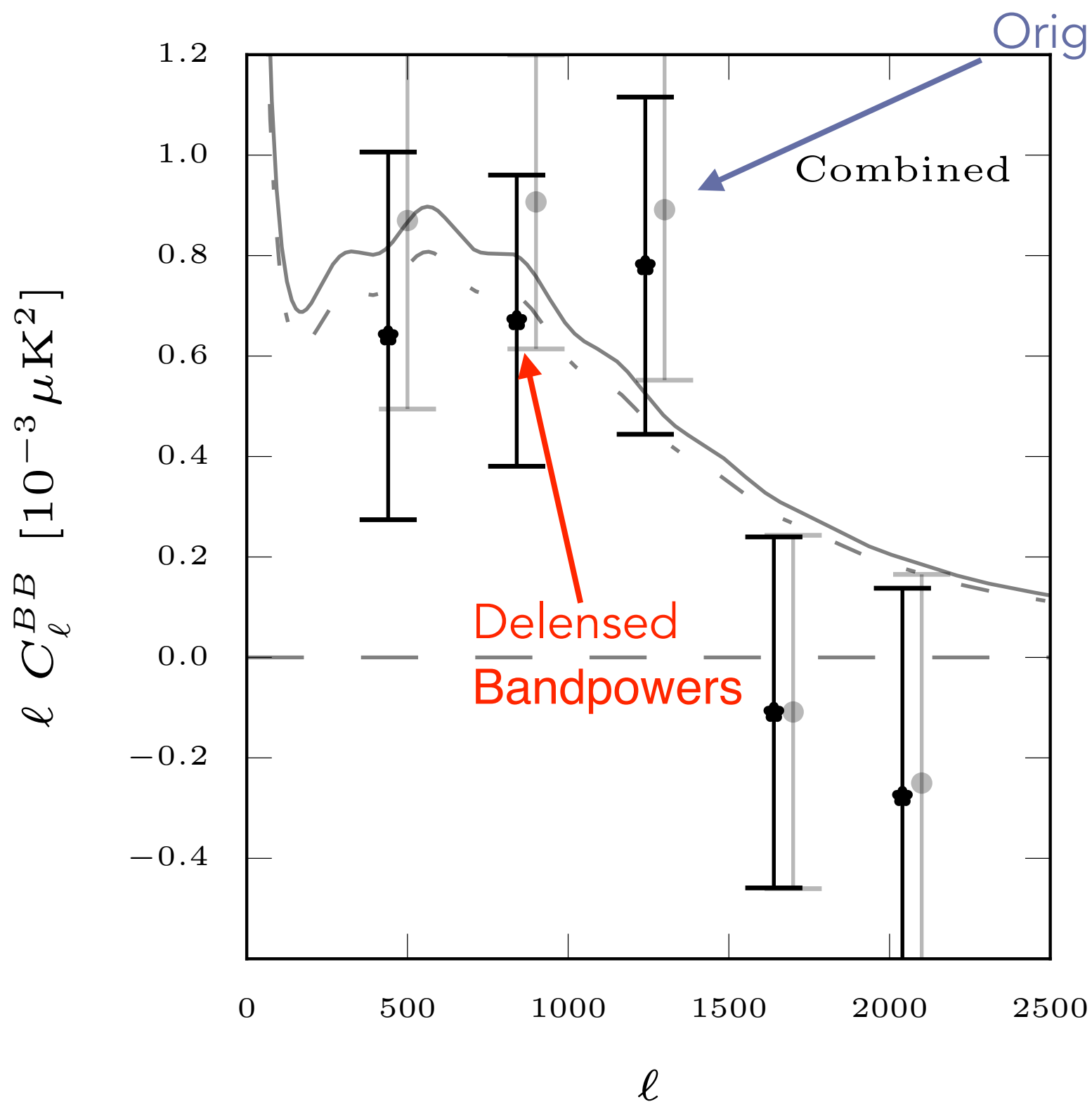
Nothing (dust, sources foregrounds) **changes** this ~**28%**

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Zero if no delensing
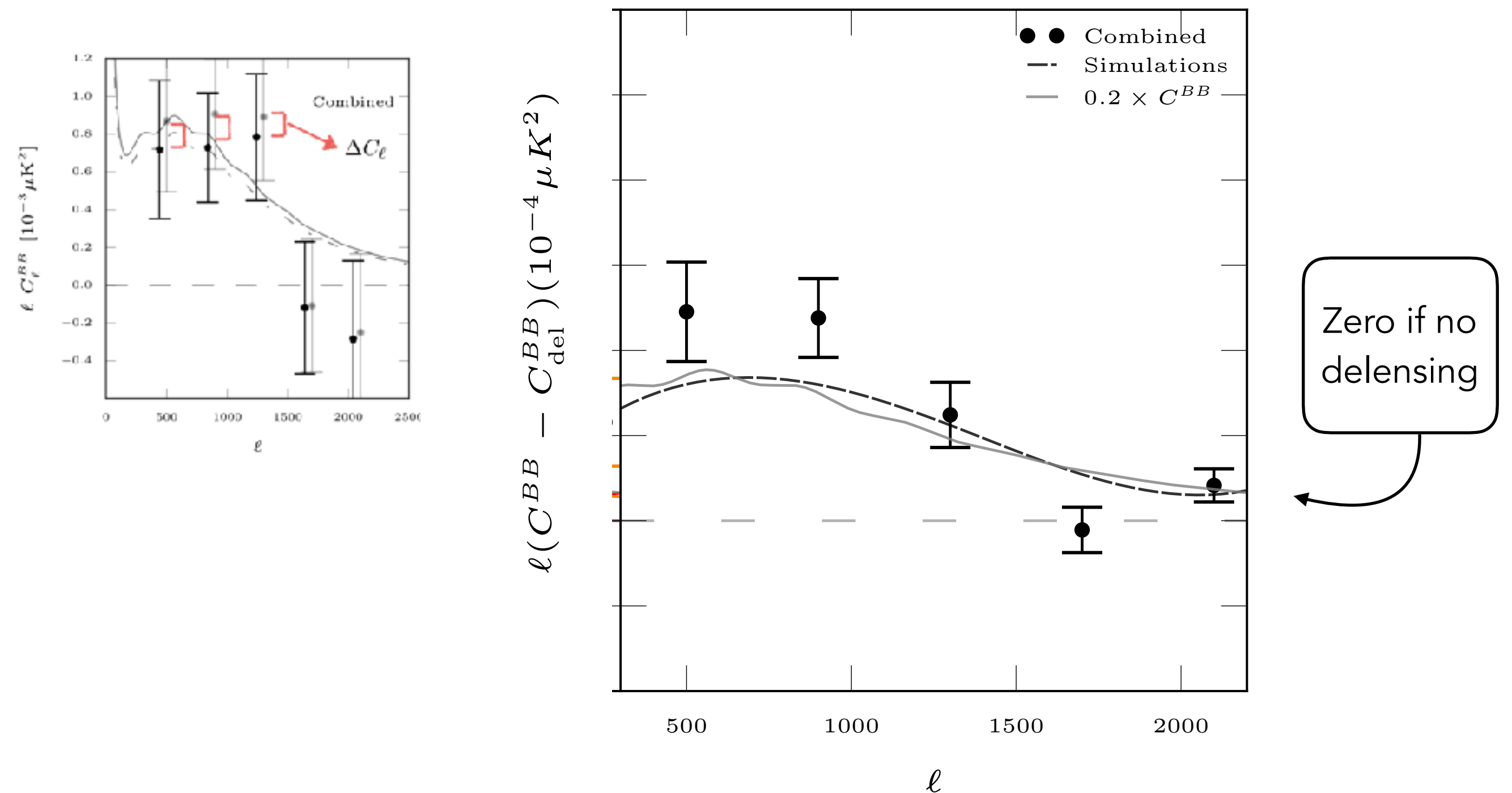
We run and passed several systematic tests.

AM at al. 1701.04396

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ROBUST: NULL AND SYSTEMATIC TESTS
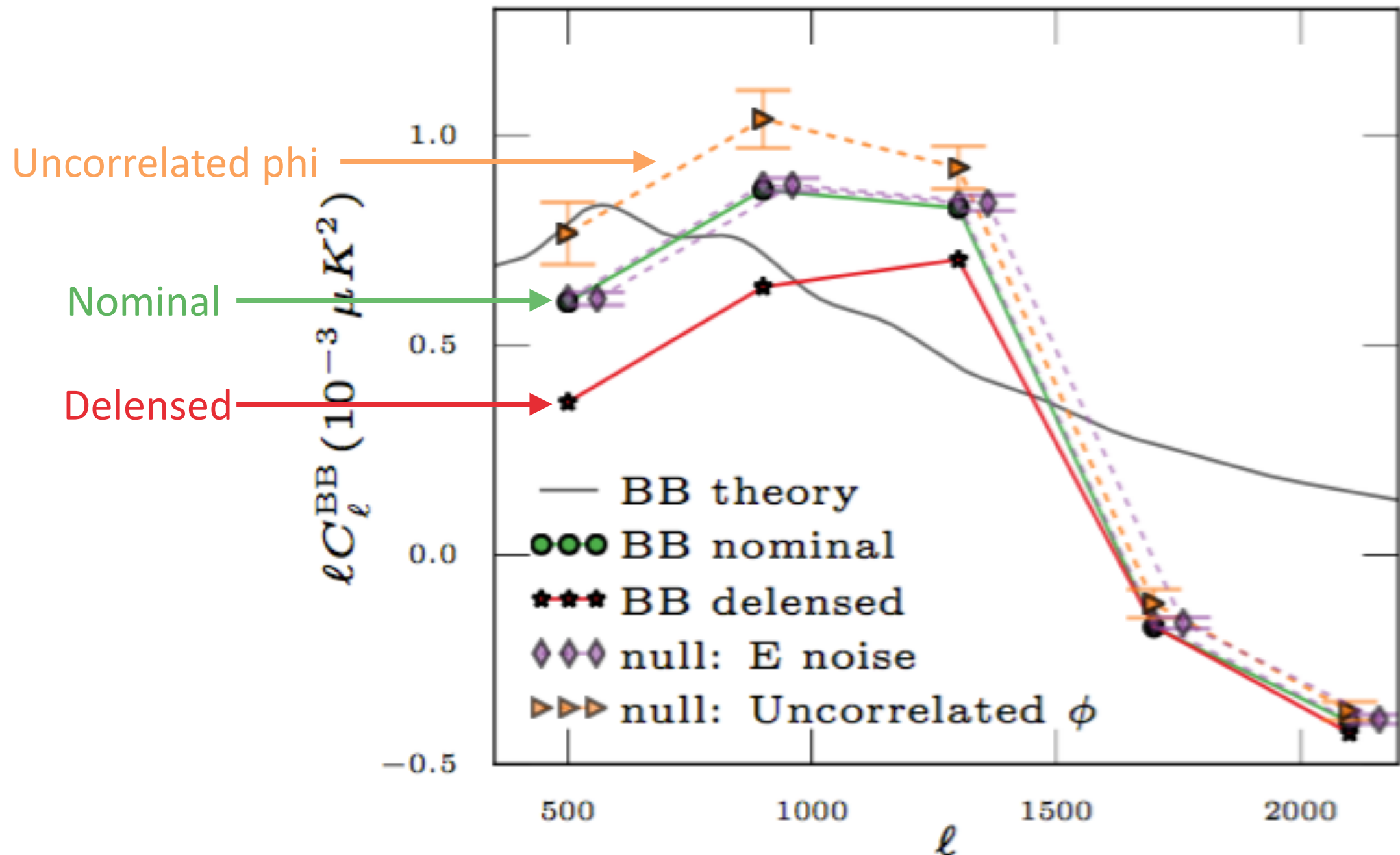
Building B-templates from E noise or uncorrelated phi **Increases** the B-mode power.

AM at al. 1701.04396

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AND THE FUTURE WILL BE EVEN BRIGHTER, DELENSING WILL IMPROVE

SIMS: DELENSING IN THE FUTURE

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

DELENSING EFFICIENCY: WHAT WE TESTED SO FAR

E_{true} noiseless, unfiltered E map; (LCDM realizations projected)

$\bar{E}_{\text{nf}}$ noiseless, filtered E map; (E_{true} with mock-observing)

$\bar{E}$ noisy, filtered E map; ($\bar{E}_{\text{nf}}$ with noise)

ϕ_{true} noiseless phi

ϕ_{CIB} CIB estimated phi

More ideal

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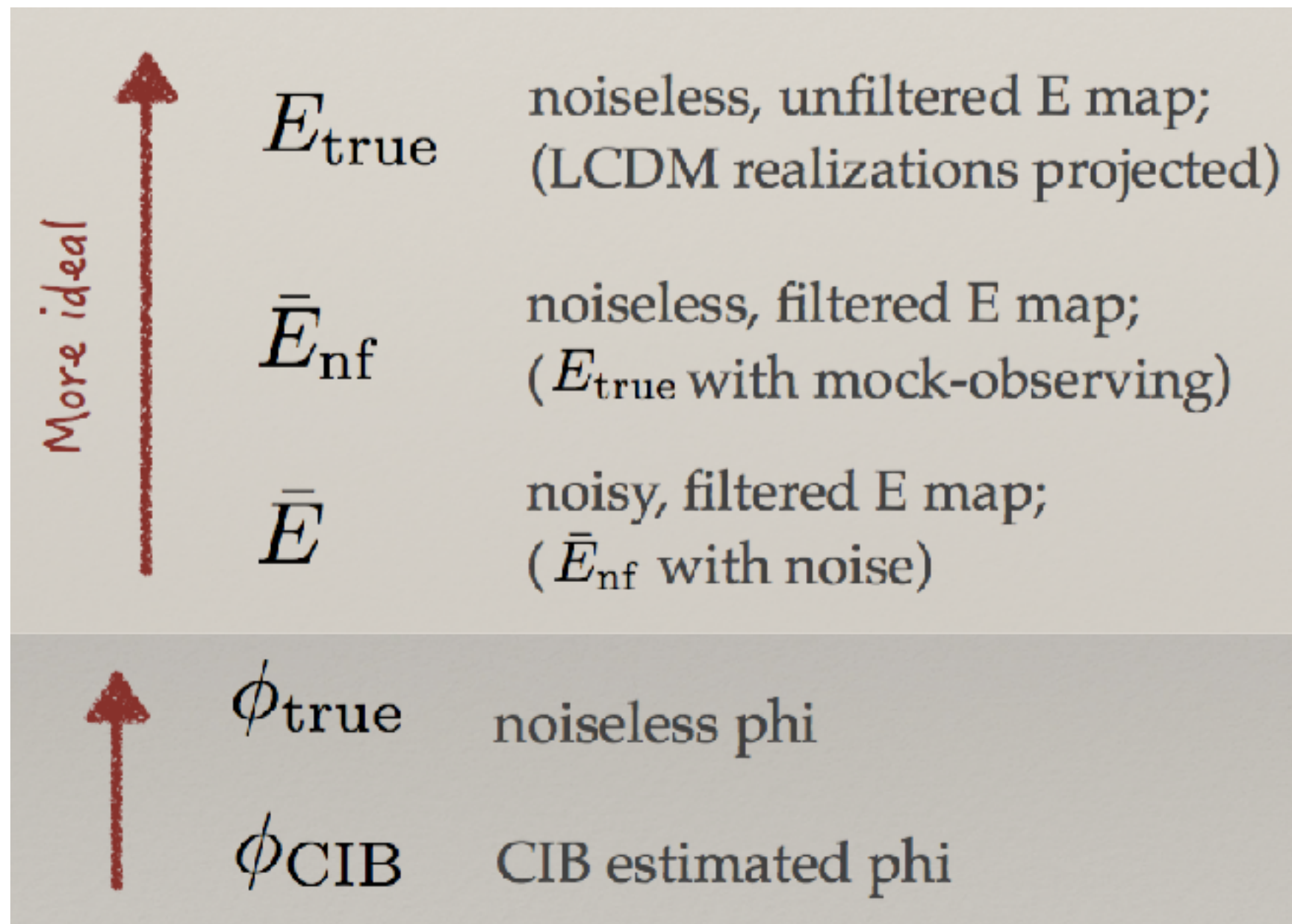
DELENSING EFFICIENCY: NOISY PHI TRACER IS THE MAIN LIMITATION

Clbb delensed /
Lensed Clbb

Worse, less
delensing

Legend:
- $\hat{B}_{\bar{E},\phi_{\mathrm{CIB}}}$
- $\hat{B}_{\bar{E},\phi_{\mathrm{CIB,model}}}$
- $\hat{B}_{\bar{E}_{\mathrm{nf}},\phi_{\mathrm{true}}}$
- $\hat{B}_{\bar{E}_{\mathrm{nf}},\phi_{\mathrm{CIB}}}$
- $\hat{B}_{\bar{E},\phi_{\mathrm{true}}^{\mathrm{Lmin=150}}}$
- $\hat{B}_{E_{\mathrm{true}}^{\ell\mathrm{xmin}=200},\phi_{\mathrm{true}}}$
- $\hat{B}_{E_{\mathrm{true}},\phi_{\mathrm{CIB}}}$
- $\hat{B}_{\bar{E},\phi_{\mathrm{true}}}$
- $\hat{B}_{E_{\mathrm{true}},\phi_{\mathrm{true}}}$

Y-axis: $C_\ell^{\mathrm{BB,delensed}}/C_\ell^{\mathrm{BB,lensing}}$

X-axis: ℓ

ϕ from CIB
corr $= 60\%$

ϕ from CIB
corr $= 80\%$

Perfect ϕ

AM at al. 1701.04396

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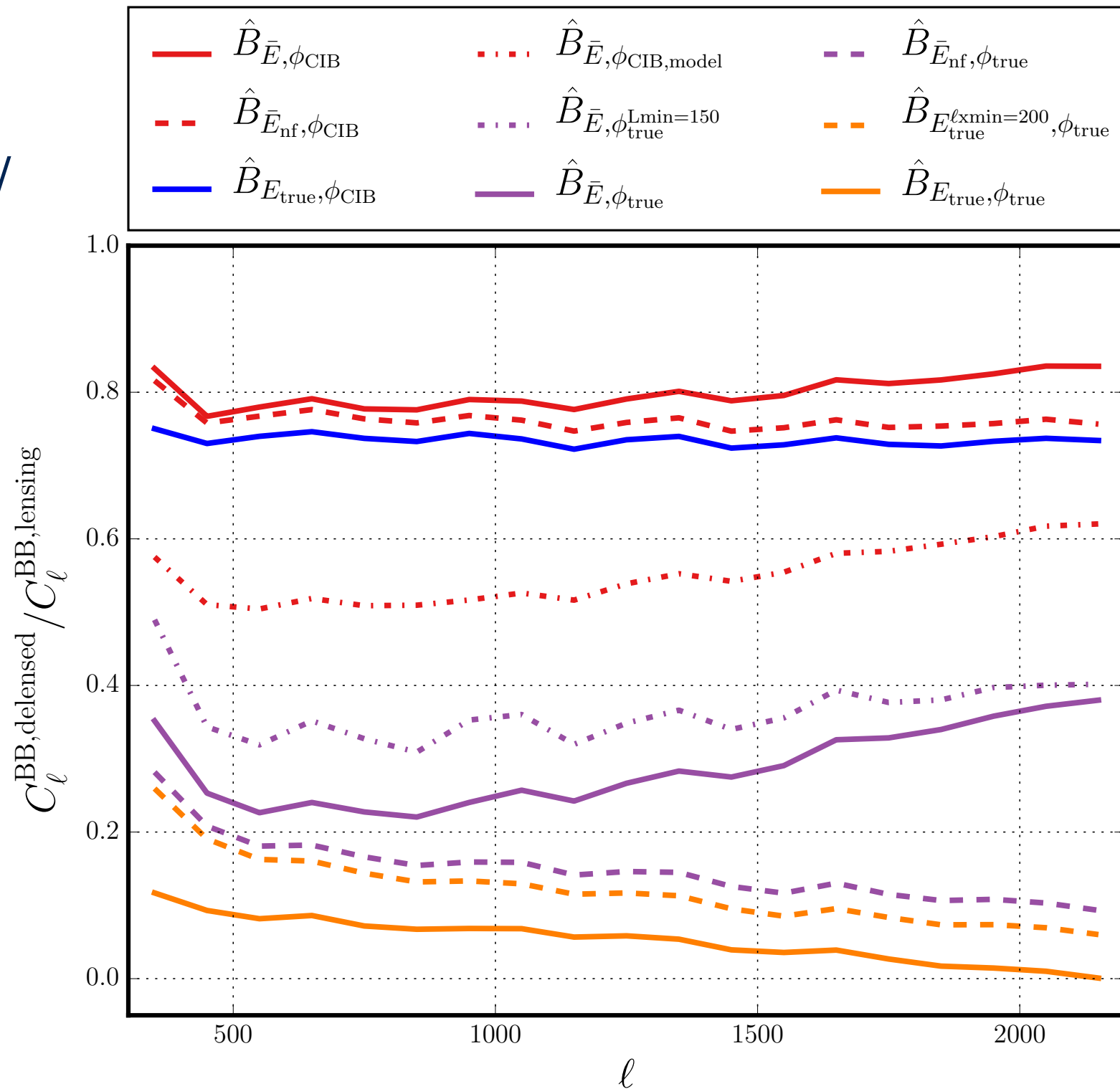
DELENSING CURRENTLY LIMITED BY NOISE IN PHI;

FUTURE FORECASTS SHOULD INCLUDE NON-IDEALITIES IN E/PHI

THE CHALLENGES: BOTH IN BUILDING AND USING THE TEMPLATE

- Building a more accurate B_{lens} template

- Use the template optimally   *Marius talk @ 15.40.*

- Understand what is left after subtraction/biases

BUILD THE TEMPLATE E-MODES AND TRACERS OF STRUCTURE

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

- Mainly from large scale potential $100 < l < 800$
- E_mode from scales slightly smaller than B_lens

Similar · **We want** · Faithful

Redshift overlap

Low Noise

CMB

In the **future,** it will be the **best tracer** for phi reconstruction.

CIB

Cosmic Infrared Background

The **best method right now.**

Galaxies

Low redshift. Still useful now. In the future to check for systematics.

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THE FUTURE OF LENSING TRACERS

| Surveys	B-mode power removed
WISE	8%
DES	14%
DESI	10%
CIB	30%
LSST	50%
SKA	50-70%
CMB Planck	8%
CMB SPTPol	35%
CMB 3G	61%
CMB S4	84%

Better CIB, DES ~DESI, LSST EUCLID WFIRST,SPTPol CMB-S3, CMB-S4

Will **improve fast! Complementarity** is **good** for **efficiency** and **robustness**!

Manzotti in preparation

Alessandro Manzotti IAP

THE FUTURE: 500D SPT, BICEP-KECK AND STAGE 3-4

Reasonable goals by middle 2018

- On the 500deg^2 SPT combine Planck CIB and CMB lensing reconstruction.
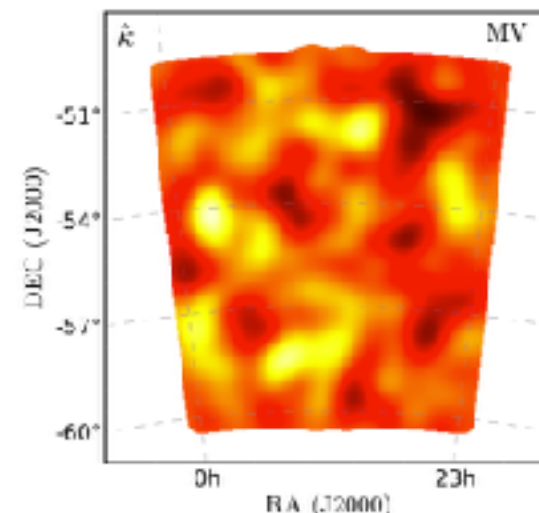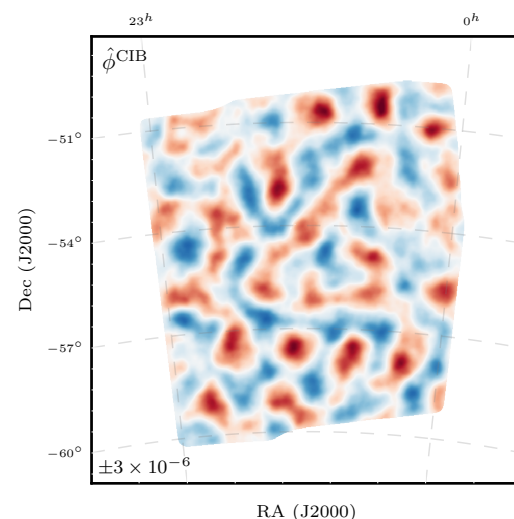
- Delens BICEP-KECK with the help of SPT

Alessandro Manzotti KICP Chicago

Paper: 1701.04396

CONCLUSION

- Delensing is crucial, and it is working. We robustly **removed 28% of lensing contamination**. The **highest B-modes delensing so far (~7 sigma)**.

- Right now all the collaborations and the **CMB Stage 4** community are **working hard to push it to 90%**.

- We need to develop **better techniques** while applying them to new **great datasets (BK+SPT3G in our case).**

Alessandro Manzotti, IAP Paris