SPT-3G Lensing Templates for South Pole Observatory

Challenges at the CMB Frontier 2026
Chino, Japan

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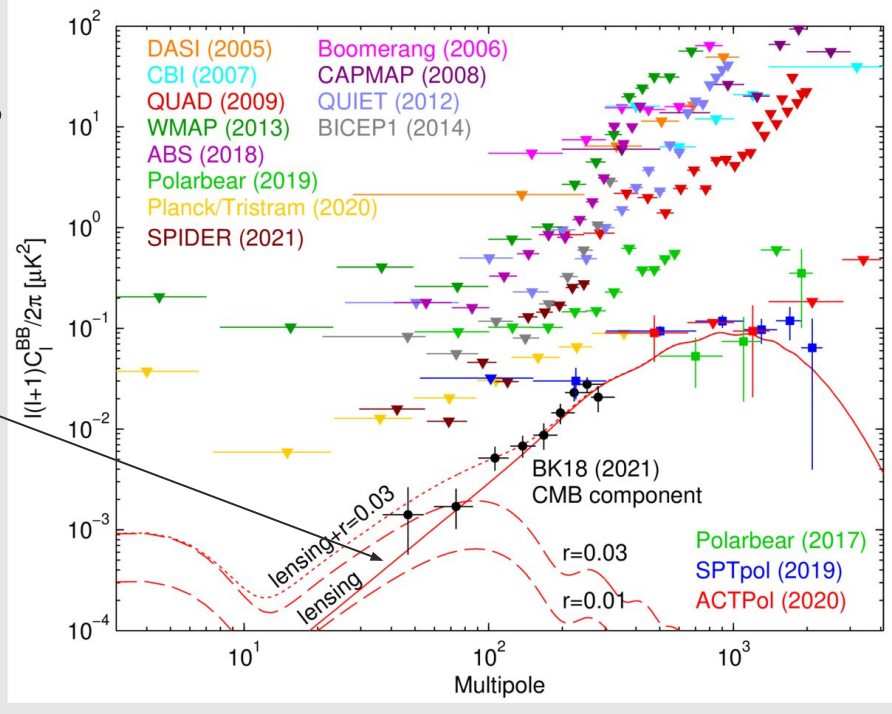
Lensing in Measurements of Primordial B Modes

- Gravitational lensing of the CMB generates B-mode polarization that contaminates measurements of primordial B modes
- In the current strongest constraint on tensor-to-scalar ratio r (BK18), lensing sample variance is already the dominant contributor to the total σ(r)

BK-XIII: Improved Constraints on Primordial Gravitational Waves Using Planck, WMAP, and BICEP/Keck Observations through the 2018 Observing Season
The BICEP/Keck Collaboration, Phys. Rev. Lett. **127**, 151301, 2021



Lensing in Measurements of Primordial B Modes

- To delens the next r analysis, need a lensing template: an estimate of lensing-induced B modes
- We present CMB lensing templates constructed with SPT-3G and Planck data
  - Foreground-robust
  - Residual lensing amplitude = 0.47 averaged over 20 ≤ ell ≤ 200 (highest delensing efficiency to date!)
  - Reduction in lensing contribution to σ(r) is directly proportional to residual lensing amplitude ⟶ reducing residual lensing amplitude directly improves σ(r)

Lensing Template

- Lensing-induced B-modes can be expressed in harmonic space as a convolution between the E-mode and the lensing potential:

Eϕ → B coupling kernel

lensed, Wiener-filtered E

$$B^{\rm lens}_{\ell m} = \sum_{\ell' m'} \sum_{LM} (-1)^M \begin{pmatrix} \ell & \ell' & L \\ m & m' & -M \end{pmatrix} f^{EB}_{\ell \ell' L} E_{\ell' m'} \phi_{LM}$$

Wiener-filtered lensing tracer

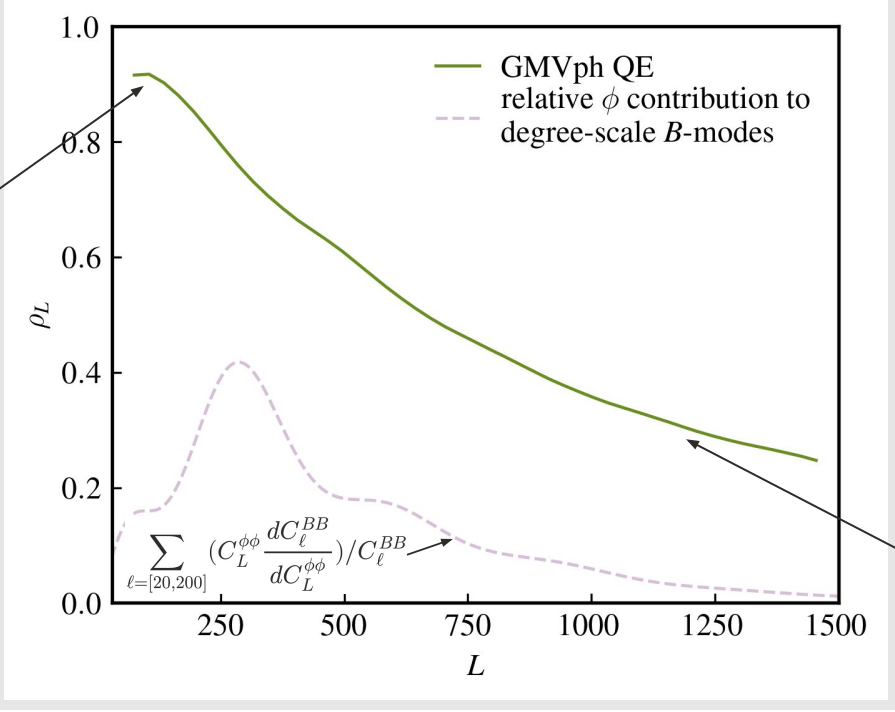
- SPT-3G 2019-2020 lensing analysis (Omori et al. in prep)
  QE reconstructed ϕ (GMV, GMVph, PP)
- Planck GNILC component-separated 545 GHz CIB

ϕ Tracers

QE internal ϕ tracer variants:
- GMV (standard MV)
- GMVph (profile-hardened)
- PP (polarization-only)

- Plot correlation coefficient between tracer and true ϕ

At low L, ρ_L^{ϕ} reaches 92%!



But not a perfect tracer of true ϕ due to noise, signal-dominated for L < 400

ϕ Tracers

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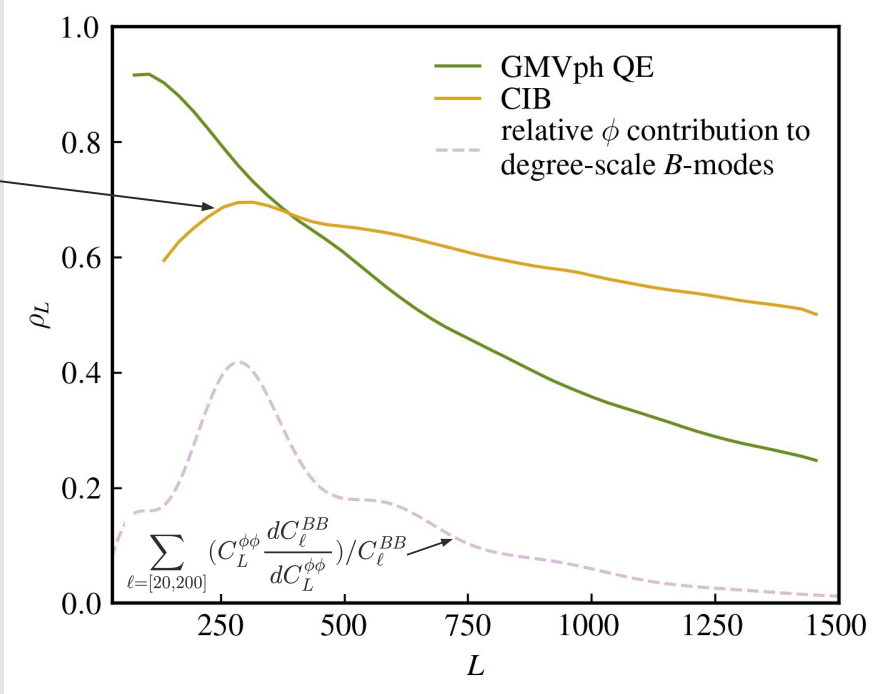
Maintains relatively constant correlation at the 60% level, even at L > 400



CIB tracer is complementary to QE-based tracers!

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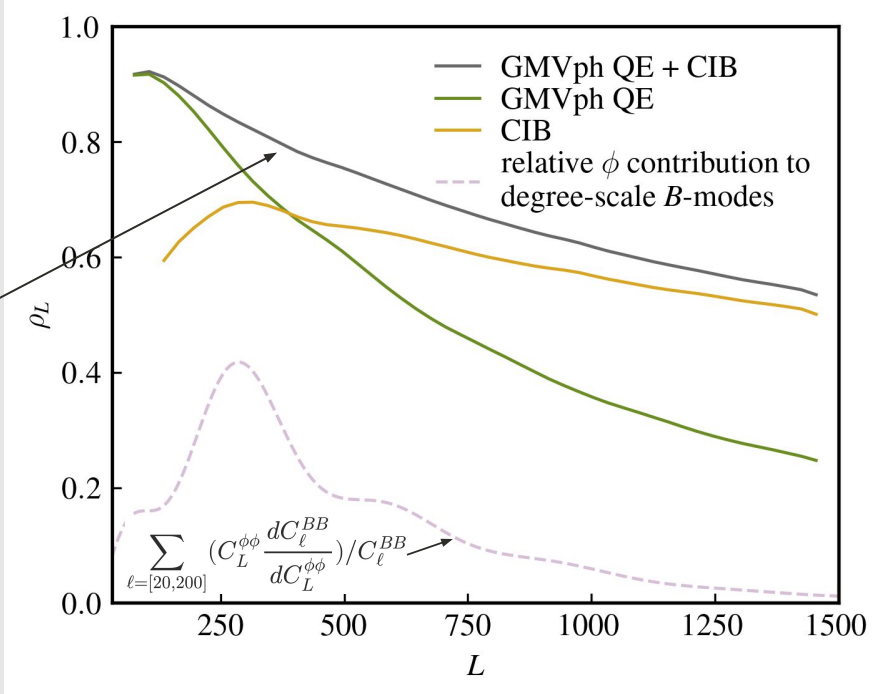
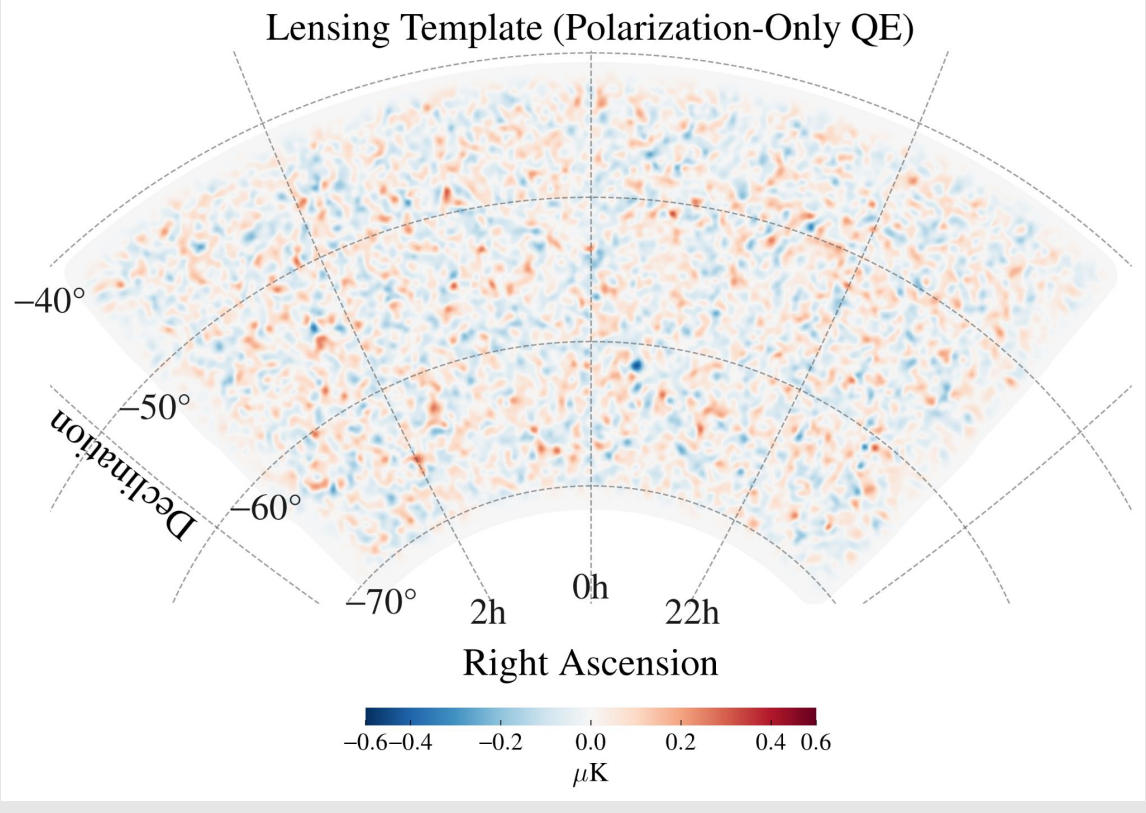
QE + CIB combined tracer improves correlation over full L range at 60-90%!



Lensing Template Maps



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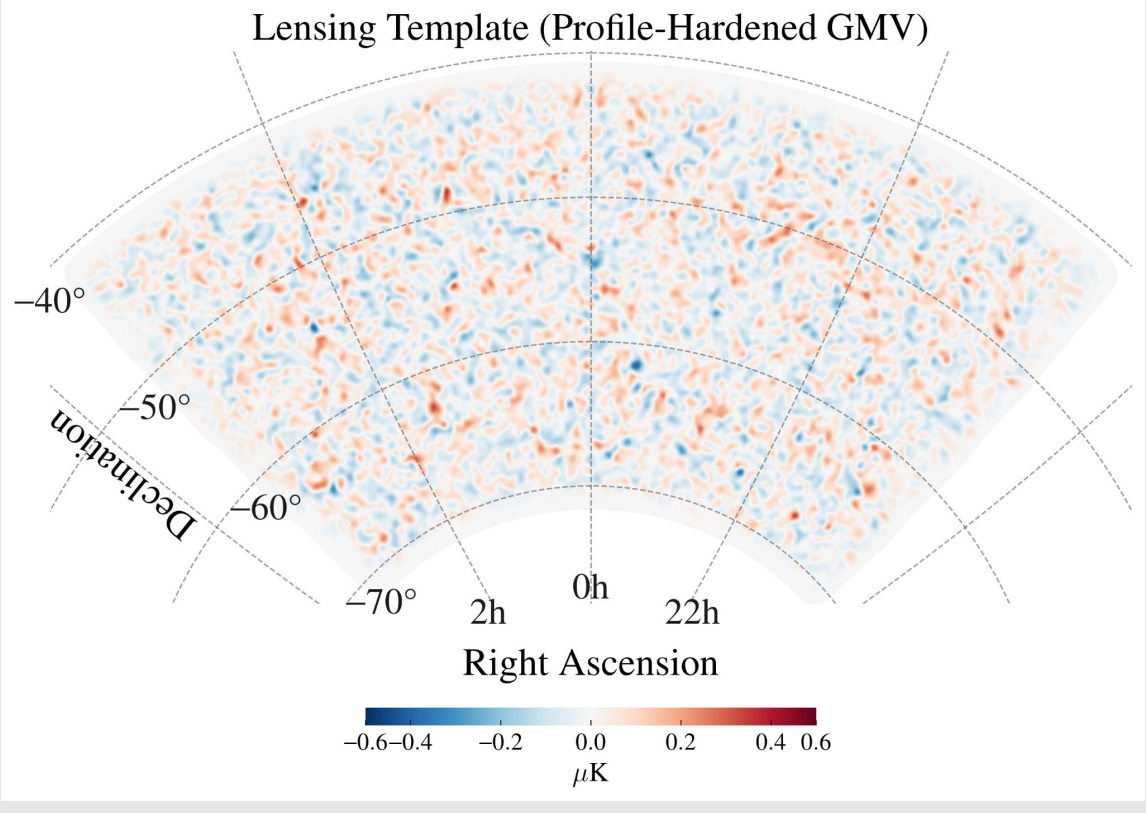

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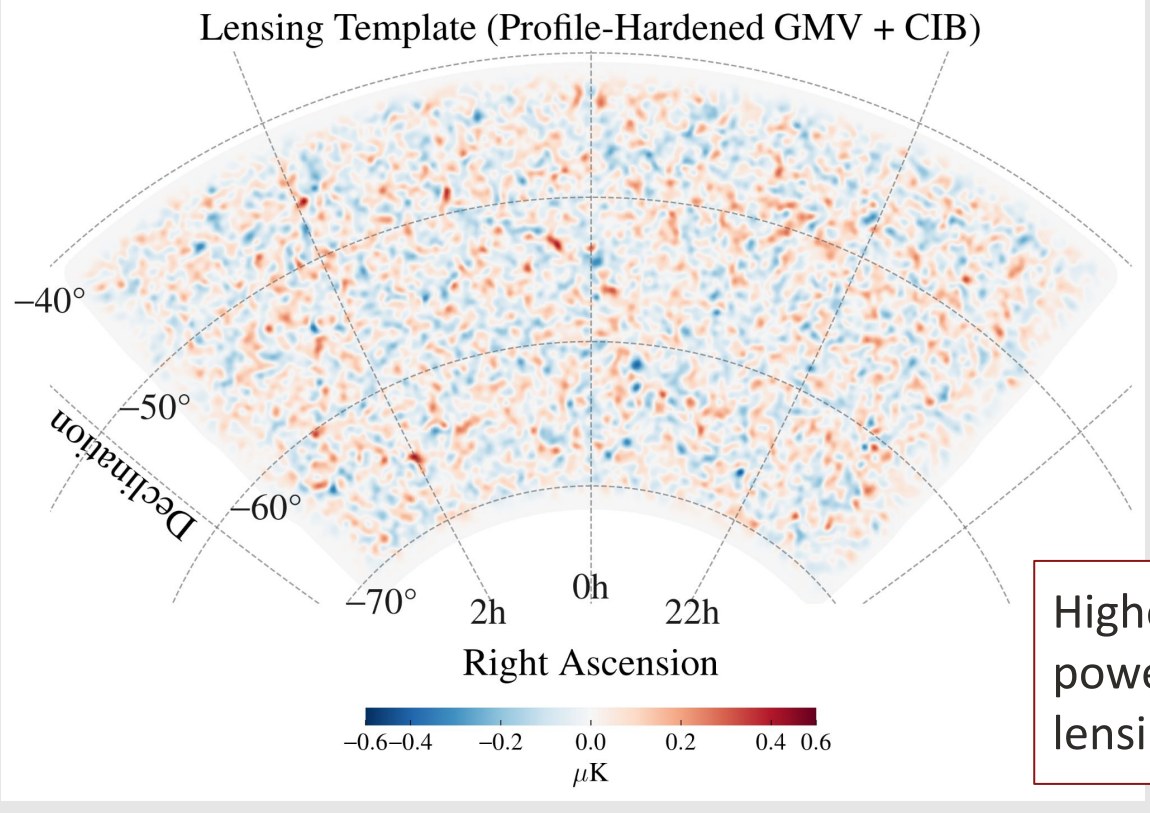
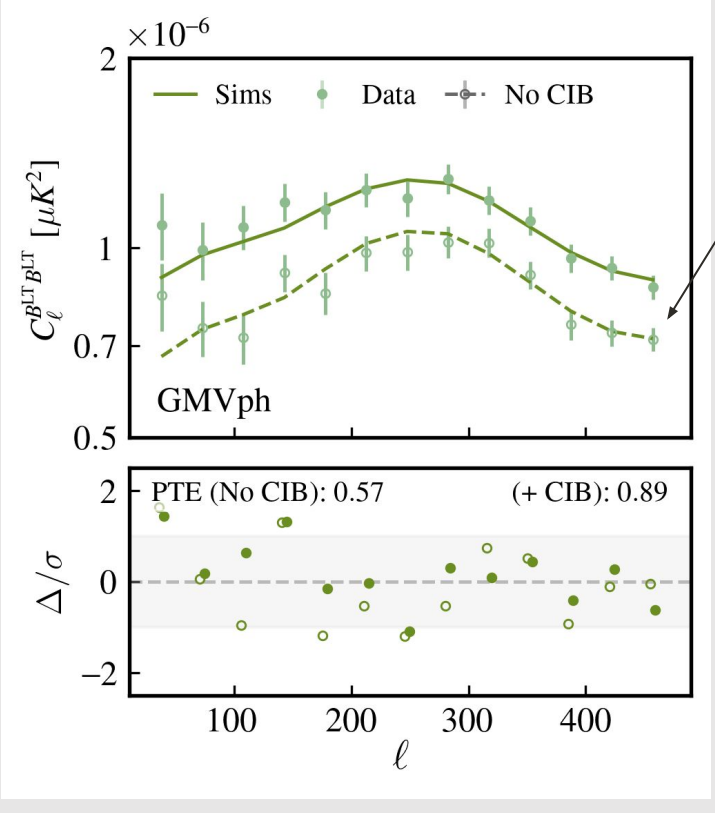


Highest ρ_L^{ϕ} = most power in resulting lensing template

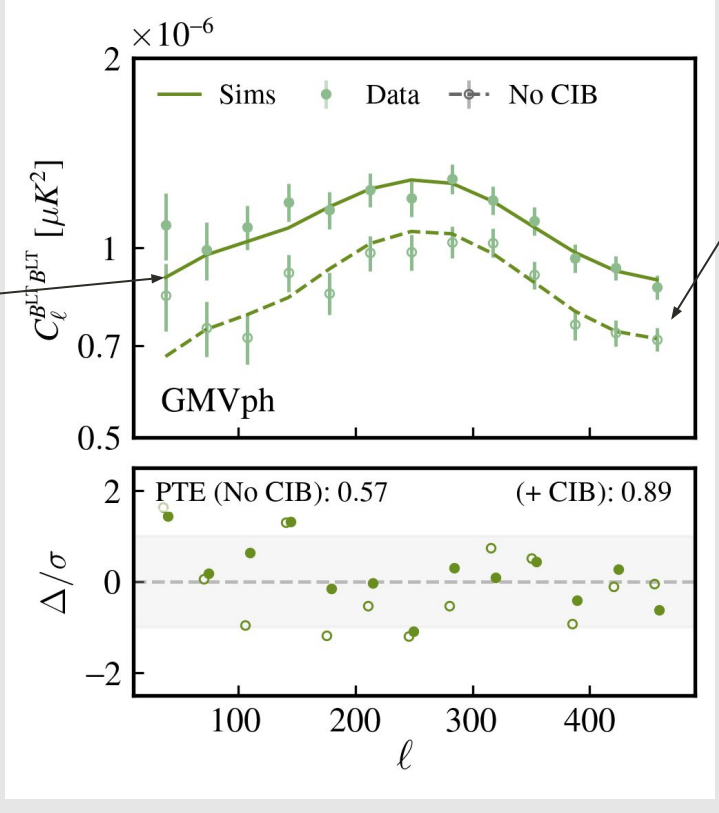
Lensing Template Spectra

Only recover a fraction of input lensing B-mode power due to tracer noise, masking/apodization, filtering



Lensing Template Spectra

Adding CIB (solid lines, filled circles) recovers more power compared to CIB-less (dashed lines, open circles) cases



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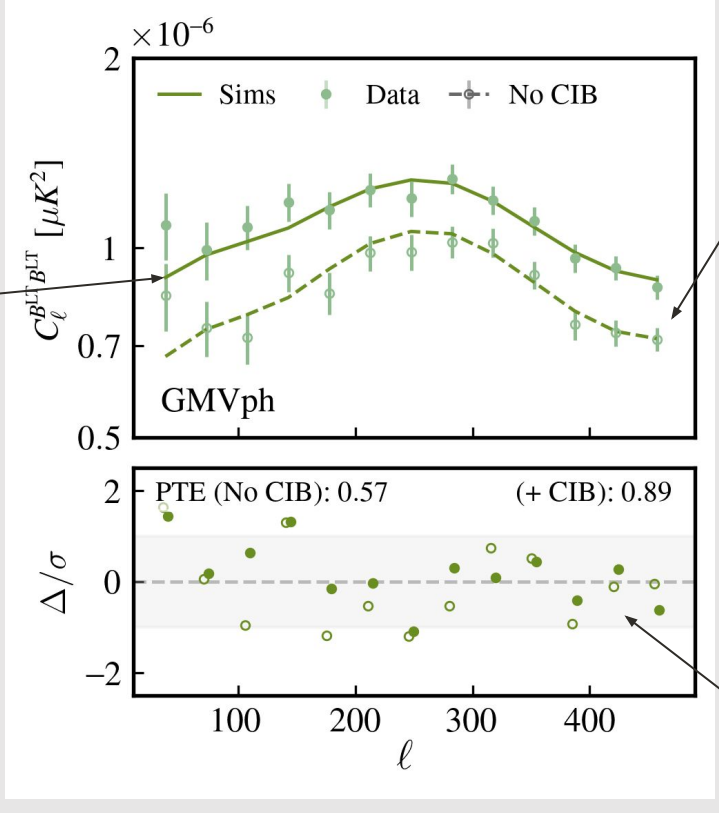

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Data auto-spectra are consistent with Gaussian-sim means = Gaussian sims provide accurate description of signal and noise in data

Delensing Efficiency

QE:	GMV	GMVph	PP
No CIB	0.59	0.60	0.68
+ CIB	0.46	0.47	0.51

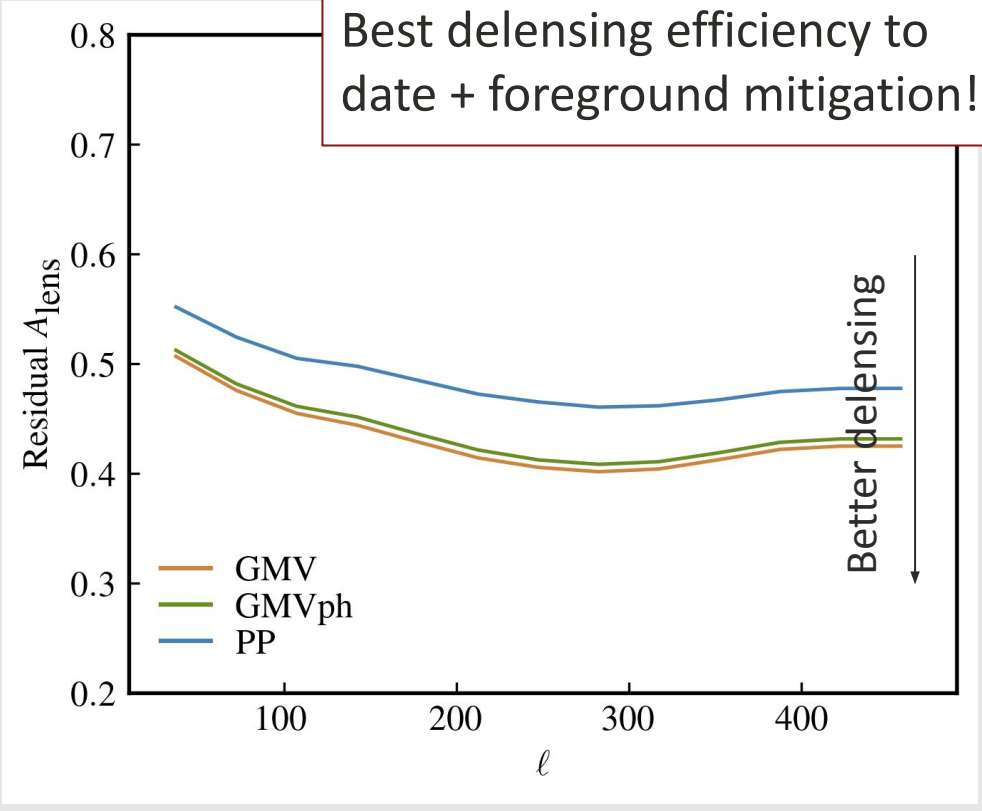
Best delensing efficiency to date + foreground mitigation!

- Compute ρ between lensing template and true lensing B

$$\rho_\ell^B = \frac{C_\ell^{B^{\rm LT} B^{\rm in}}}{\sqrt{C_\ell^{B^{\rm LT} B^{\rm LT}} C_\ell^{B^{\rm in} B^{\rm in}}}}$$

- Quantify how well we delens with residual lensing amplitude (fraction of lensing power remaining after delensing):

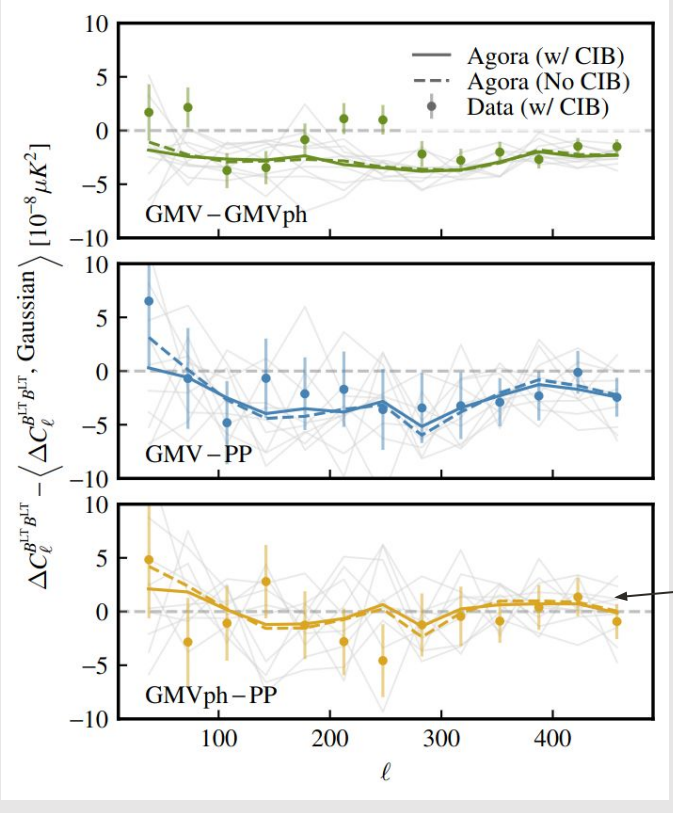
$$A_{\rm lens}^{\rm res} = \left\langle 1 - (\rho_\ell^B)^2 \right\rangle_{\ell=[20,200]}$$



Foreground Bias

GMV = standard MV
GMVph = profile-hardened
PP = polarization-only

- Using 10 Agora simulations (includes extragalactic foregrounds)
- Compare relative differences between template spectra from different tracers
- Data differences in top two panels are comparable (or less than) those of Agora



GMVph - PP is consistent with 0

- PP is largely insensitive to foregrounds → GMVph also has insignificant foregrounds

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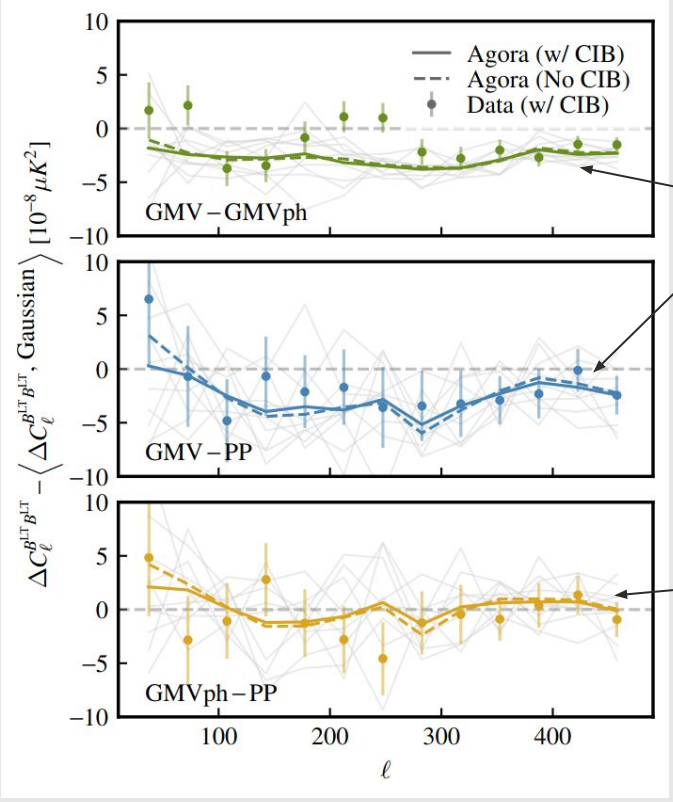

GMV - GMVph and GMV - PP show offset
- Consistent with low level of bias in standard GMV

GMVph - PP is consistent with 0
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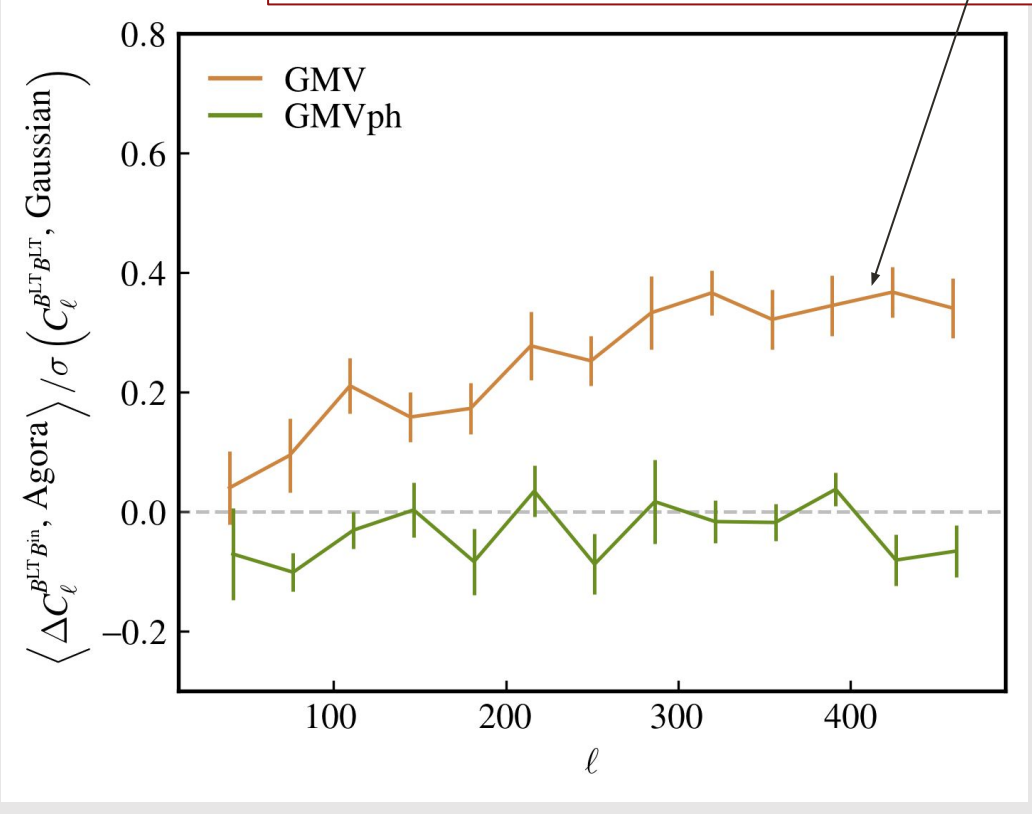
Foreground Bias

GMV
- Clear bias from foreground non-Gaussianity, consistent with contamination in the T maps

- Difference two sim sets
  - Fiducial Agora
  - Same realizations of lensed CMB and noise, but with Gaussian foregrounds
    - Gaussian foregrounds do not introduce lensing reconstruction bias



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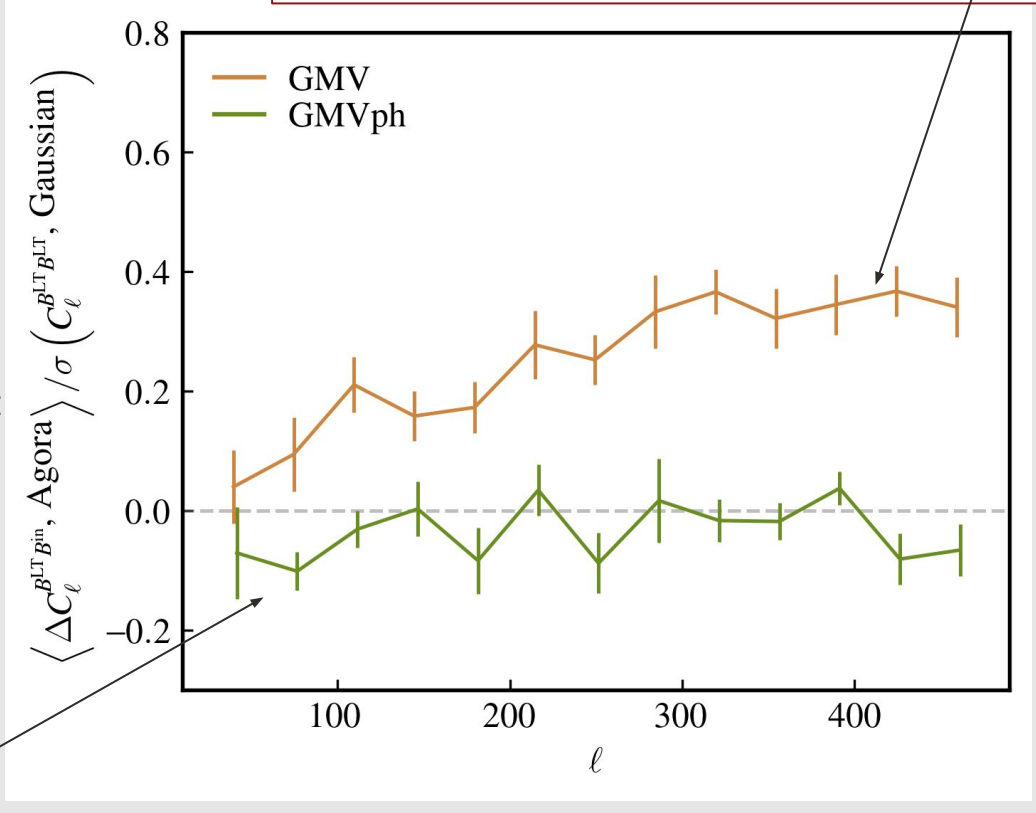

GMVph
- Significantly reduces this bias
- Foreground-induced bias is $< 0.1\sigma$, average 0.05σ (subdominant compared to statistical uncertainties)

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- Reduce residual lensing amplitude → reduce lensing contribution to B-mode variance → directly improves σ(r)
  - Back of the envelope: BK18 total σ(r) = 0.009, lensing contributes around 0.005; reduce lensing σ(r) to around 0.0024 with GMVph + CIB tracer → total σ(r) ≈ 0.0064 for BK18 delensed analysis
  - BK24 will be even more lensing dominated without delensing

Thank you!