Foregrounds and Simulations for CMB Lensing: Update and Next Steps

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For the S4 lensing group (Alex van Engelen, Neelima Sehgal, Mat Madhavacheril, Colin Hill, DW Han, Yuuki Omori, Marcelo Alvarez, Gil Holder, Kyle Story, Rupert Allison, and others)
Reminder: High Precision Lensing

- A new regime: polarization, \( \phi \sim \text{EB} \) estimator; ultra-high precision (0.2\%) power spectrum \( C_{l\phi\phi} \sim \text{EBEB} \)

- Stringent requirements for biases to lensing (\( \sim \text{EBEB} \)) and delensing
Outline

• Galactic foregrounds: simulations and biases to lensing (preliminary!)

• Requirements for foreground cleaning

• Application to delensing: the path forward

• Extragalactic foregrounds: simulations and biases
**C_{\phi\phi} Lensing Biases from Dust Polarization**

- **Unknown dust bias to lensing**, as unknown small scale non-Gaussian dust. How to estimate?
  1. Data: intensity + constant polarization angle and fraction
  2. Data: angles from HI
  3. Simulations
Estimates of $C_l^{\phi \phi}$ Dust Polarization Bias

I. Constant Polarization Angle and Fraction

- Get Q, U dust by rescaling 353 GHz Planck intensity. Measure lensing: biases appear small but non-negligible (~1%)
Estimates of $C_{l}^{\Phi\Phi}$ Dust Polarization Bias

II. HI Filament Directions to Obtain Angles

[A. v. Engelen, D. Han, N. Sehgal, S. Clark, C. Hill]

10x10 degree cutouts covering 60% of sky. In progress (complications with excess small-scale noise)
Estimates of $C_l^{\phi \phi}$ Dust Polarization Bias

III. Simulations With Magnetic Turbulence

[A. v. Engelen, D. Han, N. Sehgal]
[Vansyngel, Boulanger++ 2016]

- Median bias appears small but not negligible – $\sim$0.1-1% (60% of sky) – but: outliers! Less for 50%. Caveat: is non-Gauss. realistic?
Estimates of $C_l^{\Phi\Phi}$ Dust Polarization Bias

III. Simulations With Magnetic Turbulence

[A. v. Engelen, D. Han, N. Sehgal]
[Vansyngel, Boulanger++ 2016]

Next steps for foreground bias estimation:

- Investigate bias with more restrictive masks and higher $l_{\text{min}}$
- Finalize HI estimate and checks
- Similar analysis for synchrotron?

• Median bias appears small but not negligible – ~0.1-1% (60% of sky) – but: outliers! Less for 50%. Caveat: is non-Gauss. realistic?
Requirements for Foreground Cleaning

• Early results: one small-scale frequency channel appears insufficient.

• If with further work foregrounds remain \(\sim\) percent-level, multifrequency cleaning with dust channel will be required (+synchrotron, unless we can establish unimportance)

• What instrumental requirements are there (resolution, noise...) for successful lensing cleaning?
Foreground Cleaning – Resolution requirements?

• Assume: dust, synchrotron with known frequency scaling.

• A start: can you clean foregrounds without loss of S/N for a 5m telescope?

• Clean only E in EBEB to remove non-Gaussian bias (caveat: iteration)

<table>
<thead>
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<th>Freq. (GHz)</th>
<th>FWHM 5 m (arcmin)</th>
<th>Pol. map depth</th>
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<td>12.5</td>
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<tr>
<td>150</td>
<td>1.8</td>
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<td>1.2</td>
<td>16.3</td>
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<tr>
<td>270</td>
<td>1</td>
<td>27.9</td>
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</table>
Forecast noise levels for linear combination (ILC) with deprojection of different components
Foreground Cleaning Performance
[C. Hill, M. Madhavacheril]

ILC with deprojection: negligible lensing S/N loss for 5m telescope (c.f. 150GHz)
Foreground Cleaning Performance

[C. Hill, M. Madhavacheril]

Path forward:

- Investigate for realistic S4 configurations, find freq. + resolution limits where S/N is kept

ILC with deprojection: negligible lensing S/N loss for 5m telescope (c.f. 150GHz)
Effect on Delensing: Path Forward for Galactic Foregrounds

Focus on non-Gaussian biases
[Sherwin/Schmittfull 2015]

- Use non-Gaussian dust sims to get $\phi(EB)_{\text{dust}}$
- Make dusty delensing template
  $B_{\text{temperedust}} = E_{\text{dust}} \times \phi(EB)_{\text{dust}}$
- Estimate bias to delensing
  $B_{\text{dust}} \times B_{\text{temperedust}}$ (+ extra terms)

Dust Template / Simulation

Lensing map and B template

$\hat{B}_{\text{lens dust}}$
Outline

• Galactic foregrounds: simulations and biases
• Requirements for foreground cleaning
• Application to delensing: the path forward
• Extragalactic foregrounds: simulations and biases
Extragalactic Foregrounds – Reminder

- Both multiplicative and additive biases from T foregrounds (~few percent)
- Multifrequency data and estimator “hardening” can help – better sims useful

Fractional Lensing Biases

[van Engelen++ 2013, Osborne+++2013]
Extragalactic foregrounds – new simulations, useful for $\phi(TT)$

[M. Alvarez, G. Stein, J. R. Bond, A. v. Engelen]

- Lensed sims based on halo model + 2LPT mass distribution, with correlated CIB, tSZ, kSZ… fields
- Parallel effort on N-body sims: Fabbian++
Extragalactic foregrounds – New cross-correlation bias estimates

Yuuki Omori, Stanford/SLAC sim group

- “Multiplicative” temperature biases may be large in cross-correlation with low-z tracers (EB better?)
• Galactic foreground biases are being estimated with varied methods. Early results: dust biases ~1%, small but non-negligible; need dust channel (+synchrotron?).

• But: seems cleaning can be done with moderate resolution requirements

• Have outlined a plan for determining biases to delensing

• New extragalactic foreground simulations constructed
Backup Slides
Simulations Involving Magnetic Turbulence
50% of the sky (not 60%)

[A. v. Engelen, D. Han, N. Sehgal]
[Vansyngel, Boulanger+++ 2016]

- Outliers reduced
Effect on Delensing: Gaussian Foregrounds

- Non-Gaussian bias probably greater concern (should be able to estimate Gaussian bias, and if not, residuals are quite flat)

![Graph showing BB residuals for 5% random bias in ΔL=100 bandpowers]

Sherwin/Schmittfull 2015
What Scales Does Lensing Information Come From?

FIG. 1: Fractional contributions from $E(l)$ and $B(l)$ at $l = |l|$ to the lensing reconstruction at $L \in \{300, 800, 1500, 2000\}$ (four panels, where in each panel $l = L$ is marked with a dotted line), for the fiducial noise and resolution used in this paper. At the lower $L$ the $EE$ reconstruction (dashed lines) is mainly from squeezed shapes with $l \gg L$, however the $EB$ estimator the $E-$ and especially $B$-mode signal is important at much lower $l$ (solid lines). Mathematically what is plotted is $A_{ij}(L, l_1) \propto \int l_1 d\phi_{l_1} f_{ij}(l_1, l_2) W_{ij}(l_1, l_2)$ as a function of $l_1$, or equivalently for $l_2$ in the case of the second field in the quadratic estimator, normalized to sum to unity.