Systematic Biases on $N_{\text{eff}}$, $H_0$, and Other Parameters due to Nonlinear CMB Lensing

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CMB-S4 Collaboration Meeting, Zoom, March 2021

arXiv:2103.05582
w/ Fiona McCarthy, Mathew Madhavacheril
CMB Lensing

Extremely important effect on primary CMB power spectra at high ell

\[ C_{\ell}^{TT} \]
\[ \ell(\ell+1)C_\ell/(2\pi) \text{ [\(\mu\)K]}^2 \]
- lensed
- unlensed
- SO+Planck noise (incl. fg.)
- S4+Planck noise (incl. fg.)

\[ C_{\ell}^{EE} \]
\[ \ell(\ell+1)C_\ell/(2\pi) \text{ [\(\mu\)K]}^2 \]
- lensed
- unlensed
- SO+Planck noise (incl. fg.)
- S4+Planck noise (incl. fg.)

\[ C_{\ell}^{TE} \]
\[ \ell(\ell+1)C_\ell/(2\pi) \text{ [\(\mu\)K]}^2 \]
- lensed
- unlensed

McCarthy, JCH, & Madhavacheril (2021)

Simons Obs. post-comp.-sep. noise computed by JCH in 1808.07445
CMB-S4 post-comp.-sep. noise computed by JCH in 1907.04473
CMB Lensing

Nonlinear evolution and baryonic effects alter the lensing power

Seven hydro sims:

McCarthy, JCH, & Madhavacheril (2021) see also McCarthy et al. (2020)
Potential Parameter Biases

This can produce surprisingly large biases on, e.g., $H_0$, $\omega_c$, and $N_{\text{eff}}$ for upcoming CMB experiments (not current!)

Usual approach in primary CMB analyses to date: “set it (default Halofit or HMcode in CAMB or CLASS) and forget it”

This will not suffice for CMB-S4! (or Simons Observatory)

McCarthy, JCH, & Madhavacheril (2021)
Potential Parameter Biases

This can produce surprisingly large biases on, e.g., $H_0$, $\omega_c$, and $N_{\text{eff}}$ for upcoming CMB experiments (not current!)

- $1.6\sigma$ bias on $H_0$
- $1.6\sigma$ bias on $\omega_c$
- $1.2\sigma$ bias on $N_{\text{eff}}$
- $2\sigma$ bias on $\omega_c$

Not an issue for Planck or for current ACT/SPT data

McCarthy, JCH, & Madhavacheril (2021)
Mitigation Methods

Three strategies

1) Explicitly cut all TT data at $\ell > 3000$ (w/ small penalty in final parameter error bars) — 13% increase in $\sigma(N_{\text{eff}})$ for S4
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Works for all sims tested:

![Graph showing Abs(Bias)/$\sigma$ vs. $\ell_{\text{max}}$](image)
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2) Marginalize over parameters describing baryonic effects — but pay a penalty in parameter error bars: 13% increase in \( \sigma(N_{\text{eff}}) \) for S4 [coincidentally same as above]
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3) Delens the T and E-mode maps using the reconstructed $\kappa$ map (and/or external tracers like the CIB)
   —> Most robust, data-driven approach, and can actually improve the error bars on parameters [Green et al. (2016)]
   —> Challenge: need very high-L $\kappa$ information!

McCarthy, JCH, & Madhavacheril (2021)
Aside: Boltzmann Accuracy

The default accuracy settings in CAMB or CLASS will no longer suffice for upcoming CMB data sets — higher-accuracy lensing is needed (easy to fix!)

Even for current data from ACT/SPT, using high-accuracy settings is necessary for precise $\chi^2$ comparison of $\Lambda$CDM to some extended models (EDE, etc.)

McCarthy, JCH, & Madhavacheril (2021)
Take-Home Messages

1) Baryonic feedback effects must be accounted for in upcoming primary CMB power spectrum analyses
2) Crank up your precision settings in CAMB/CLASS
3) What other effects do we need to be thinking about at this level of precision? [for discussion]

Thanks!