Higher-Order Corrections to CMB Lensing Cross Correlations

CMB-S4 Workshop, Sept 06-08, 2018, Princeton

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Higher Order in ?

Non-linear physical processes → Non-Gaussian lensing deflections

- Non-linear gravitational evolution
- Multiple deflections

- small corrections → perturbative modeling
- Importance for CMB-S4:
  - probably yes!
  - depends on Observable and Estimator
Higher order: Quadratic Estimator

\[ \hat{\kappa} \propto \langle \tilde{T}\tilde{T} \rangle \]

Lensed CMB is non-linear in lensing

\[ \tilde{T} = T(\vec{x} + \Delta \vec{x}) \sim T(\vec{x}) \left[ \kappa^{(1)}(\vec{x}) + \kappa^{(2)}(\vec{x}) + O(\delta_{m}^{3}) \right] \]
Higher order:

Quadratic Estimator

\[ \hat{T} = T(\hat{x}) + \Delta \hat{x} \sim T(\hat{x}) \kappa^{(1)}(\hat{x}) + \kappa^{(2)}(\hat{x}) + O(\delta_m^3) \]

Lensed CMB is non-linear in lensing

total (relative) deflection is non-linear in lensing

\[ \hat{k} \propto \langle \hat{T} \hat{T} \rangle \]
Higher order: Quadratic Estimator

\[ \hat{\kappa} \propto \langle \tilde{T} \tilde{T} \rangle \]

Lensed CMB is non-linear in lensing

\[ \tilde{T} = T(\tilde{x} + \Delta \tilde{x}) \sim T(\tilde{x}) \left[ \kappa^{(1)}(\tilde{x}) + \kappa^{(2)}(\tilde{x}) + \mathcal{O}(\delta^3) \right] \]

Total (relative) deflection is non-linear in lensing

Non-linear gravitational evolution
Higher order in Cross Correlation

\[ C_L^{\hat{k}\delta_{\text{ext}}} \sim \langle \tilde{T}\tilde{T}\delta_{\text{ext}} \rangle \]

LO: \[ C_L^{\hat{k}\delta_{\text{ext}}} \sim \langle \kappa\delta_{\text{ext}} \rangle \]

NLO: \[ C_L^{\hat{k}\delta_{\text{ext}}} \sim \langle \kappa\kappa\delta_{\text{ext}} \rangle \]

→ estimator picks up cross-bispectra

→ all combination of \( \mathcal{O}(\delta_{\text{lin}}^4) \sim \mathcal{O}[(P_{\delta}^{\text{lin}})^2] \)

→ results in ‘bias’

\( \delta_{\text{ext}} \): - Galaxy Clustering
- Weak Lensing
- etc.
Non-linear Bias for CMB-S4 on X with Galaxy Clustering

- LSST-like
- linear bias

Total Bias/Noise up to 15 σ

VB et al in prep.
Non-linear Bias for CMB-S4 on X with Galaxy Clustering

- LSST-like
- linear bias

\[ \left\langle \tilde{T} \nabla \tilde{T} \right\rangle \rightarrow \left\langle \tilde{T} \nabla \tilde{T}(\ell < 2000) \right\rangle \]

Hu et al. 2007

Total Bias/Noise up to 15 \( \sigma \)

VB et al in prep.
Non-linear Bias for CMB-S4 on X with Galaxy Clustering

Bias on $C_L^{\hat{g}}$, EB-estimator, $l_{max}=4000$

- LSST, full redshift range

total S/N $\sim 480$

total bias/noise $\sim 9$

VB et al in prep./ Prelim!
Conclusions & More

- All corrections?

\[ C_L^{\hat{\kappa}\delta_{\text{ext}}} \sim \langle \tilde{T}\tilde{T}\delta_{\text{ext}} \rangle \]

Correlation is with deflected fields!

\[ \delta_{\text{ext}}(\bar{x} + \Delta \bar{x}) \]

VB, Chirag Modi and Emanuele Castorina in prep.

- Non-linear corrections can be important for any CMB lensing estimator*

→ Tests on suitable simulations

*that does not model the lensing non-linearities
Non-linear Bias for CMB-S4 on X with Galaxy Clustering

Bias on $C_L^{kg}$, TT-estimator, $l_{max}=4000$

$f_{sky} = 0.5$

- $z=0.0-0.5$, $n=14.3$ arcmin$^{-2}$
- $z=1.0-2.0$, $n=21.6$ arcmin$^{-2}$
- $z=3.0-4.0$, $n=1.5$ arcmin$^{-2}$

Total Bias/Noise up to 15 $\sigma$
Non-linear Bias for CMB-S4
CMB Lensing X Weak Lensing

Bias on $C^{κκ_{CMB}}$ from TT-Estimator, $l_{max}=4000$

- Blue line: $z_s=1.0$
- Orange line: $z_s=2.5$

Bias/Signal in %

$L$

Bias on $C^{κκ_{CMB}}$ from TT-Estimator, $l_{max}=4000$

- Blue line: $z_s=1.0$
- Orange line: $z_s=2.5$

Bias/Signal in %

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Bias on $C^{κκ_{CMB}}$ from TT-Estimator, $l_{max}=4000$

- Blue line: $z_s=1.0$
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Bias/Signal in %

$L$
Redshift Distribution