CMB Lensing reconstruction using cut sky polarization maps and pure B modes

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Outline

- Review of CMB
- CMB lensing
- CMB polarization
- CMB lensing reconstruction: polarization
- Summary
Evolution of the universe

CMB temperature power spectrum

CMB Lensing

Last scattering surface

Inhomogeneous universe - photons deflected

Observer
CMB lensing order of magnitudes

(set \( c = 1 \))

\[
\begin{align*}
\psi & \quad \beta \\
\text{Newtonian argument: } & \beta = 2 \psi \\
\text{General Relativity: } & \beta = 4 \psi \quad (\beta \ll 1)
\end{align*}
\]

Potentials linear and approx Gaussian: \( \psi \sim 2 \times 10^{-5} \)

\( \beta \sim 10^{-4} \)

Characteristic size from peak of matter power spectrum \( \sim 300 \) Mpc

Comoving distance to last scattering surface \( \sim 14000 \) Mpc

\( \Rightarrow \) pass through \( \sim 50 \) lumps \( \Rightarrow \) total deflection \( \sim 50^{1/2} \times 10^{-4} \)

\( \sim 2 \) arcminutes

(ignores angular factors, correlation, etc.)
CMB Polarization

Generated during last scattering (and reionization) by Thomson scattering of anisotropic photon distribution.

Observed Stoke’s Parameter

\[ \mathcal{P}_{ab} = \nabla (a \nabla b) P_E - \epsilon^c (a \nabla b) \nabla c P_B \]

“gradient” modes
E polarization

“curl” modes
B polarization

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Why Measure the Polarization?

- **Virtues of polarization**
  - generated by scattering only
  - Tensor field on the sky

- **Uses of polarization**
  - verify the gravitational instability paradigm
  - probe the reionization epoch
  - get higher statistics on the acoustic peaks and their underlying parameters
  - reconstruct the scalar, vector, tensor nature of the perturbations and hence the cosmology even if ab initio models are wrong
  - test inflationary models by measuring the gravitational wave amplitude
CMB lensing reconstruction

• A full maximum likelihood based analysis
  – Most optimal but computationally challenging (numerically expensive inverse-variance filtering)

• Quadratic estimator approximation
  – Useful but not optimal
  – Nearly optimal for current generation experiments once generalized for partial sky coverage and inhomogeneous noise
CMB lensing reconstruction: Polarization

- Flat sky approximation
- Cut sky and E/B leakage
- Pure B modes

Polarization reconstruction without Boundaries
CMB lensing reconstruction: Polarization

Apodization window

Map for $\hat{d}_{EE}^{\text{cut}}$

Map for $\hat{d}_{EE}^{\text{pure}}$

Map for $\hat{d}_{EB}^{\text{cut}}$

Map for $\hat{d}_{EB}$
CMB lensing reconstruction: Polarization

Without E/B separation

Residual biases

Using pure B modes
CMB lensing reconstruction: Polarization

Comparison of noise bias reconstruction on the period and non periodic sky patches

Reconstruction errors
Summary

- Require more detailed study for small systematic deviations from analytic results for a periodic patch.

- Using pure B modes significantly reduces the variance in the power spectrum reconstruction.

- Quadratic estimator on the cut sky is a simple alternative to more numerically costly, pertubatively optimal estimators for current-generation CMB polatization measurement.