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Hybrid Delta-map: Combining Harmonic and Real-space Methods for CMB Foreground Removal

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The B-mode polarization of the cosmic microwave background (CMB) is a sensitive probe of primordial gravitational waves. A precise measurement of the tensor-to-scalar ratio r enables stringent tests of inflation, yet the B-mode signal is hidden beneath Galactic foregrounds. Delta-map approximates the line-of-sight dependence of the foreground spectral energy distribution to first order, capturing spatial variation in frequency scaling. We present Hybrid Delta-map, which retains Delta-map's first-order line-of-sight expansion of the foreground SED while modeling the foregrounds in a spherical-harmonic basis restricted to the multipoles actually retained in the analysis ($\ell \leq \ell_{\rm max}$), and then projects back to real space to build the likelihood. This preserves the advantages of real-space analysis (e.g., flexible masking), enforces strict control of $\ell_{\rm max}$, and removes the mismatch that arises when fully pixel-space fits at high resolution carry more free parameters than a band-limited data set ($\ell \leq \ell_{\rm max}$) can support—an imbalance that can bias r. In realistic multi-frequency simulations including beams, sky masking, and instrument noise, Hybrid Delta-map shows no statistically significant bias in estimates of r at the reionization bump (within our simulation precision) and reduces computational cost.
![Estimates of r from the Extended Delta-map (red) and the Hybrid Delta-map (blue)

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