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## Modeling and Mitigating Half-Wave Plate Systematics in CMB Polarization Measurements

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We investigate the impact of non-ideal half-wave plates (HWP) on CMB polarization measurements in experiments such as the Simons Observatory and LiteBIRD. Because both foreground emission and instrumental effects vary with frequency, they are closely intertwined, and addressing one without the other can interfere with our estimation of cosmological parameters.

Through end-to-end simulations, we demonstrate that neglecting HWP frequency dependence produces significant polarization leakage, skewing foreground spectral parameters and leading to substantial bias in the  $B$ -mode power spectrum. We propose a JAX-based component separation framework that explicitly incorporates the non-ideal HWP response, enabling a joint treatment of instrumental effects and astrophysical components.

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