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Implementation Aspects of Dynamic Projection Induced Polarimetry for Ground-based Sky Averaged 21-cm Experiments

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In contrast to large interferometric arrays, by using a single broad-band antenna or a small compact array, global (or sky-averaged) 21-cm experiments offer a complementary and experimentally simpler means to measure the redshifted cosmological neutral hydrogen spin-flip 21-cm transition for studying the thermal and ionization history of the intergalactic medium (IGM) in the early Universe. Due to discrepancies with standard IGM 21-cm models and data analysis concerns, many speculations have been raised on the nature of a recently reported absorption feature at 78 MHz by EDGES (Experiment to Detect the Global EoR Signature) [1]. Plausible explanations include both unaccounted systematic artifacts and potential new physics, as summarized in [2].

It is imperative to develop an independent approach to better characterize and mitigate some of these systematics. The goal of this work is to present an overview on constraining the global 21-cm signal with the dynamic projection-induced polarimetric effect (PIPE) [3, 4]. As a beam-weighted measurement, the spectrally smooth foreground synchrotron emission is corrupted by the frequency-dependent antenna response. This complicates the conventional polynomial-fitting foreground removal approach for recovering the five order-of-magnitude weaker 21-cm signal. However, by exploiting the inherent polarization leakage of a dual-polarized antenna, as a pure geometric effect, the projection of an anisotropic foreground on the antenna plane induces distinct signatures in the Stokes parameters. These signatures help to differentiate the foreground from the isotropic 21-cm signal, which is expected to be present only in the total intensity Stokes I due to symmetry. By applying a pattern recognition based analysis pipeline, `pylinex` [5], [6] illustrated that both time and polarization information, which a single time-averaged total-power spectrum lacks, are needed together to simultaneously constrain the beam-weighted foreground and the embedded 21-cm signal to higher confidence.

Our testbed instrument, the Cosmic Twilight Polarimeter (CTP), consists of a dual-polarized antenna to conduct full Stokes observation for the PIPE. Drawn from lessons learned in previous prototypes, we will present the optimization framework used for upgrading the CTP by applying `pylinex` on our end-to-end PIPE simulations. Particularly, we will focus on performance metrics for the instrument's square patch antenna design, balanced correlation receiver calibration scheme, and observation strategies.

References

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