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BayesEoR: Bayesian 21-cm Power Spectrum Estimation from Interferometric Visibilities

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Statement of need

The highly redshifted 21-cm signal from neutral hydrogen in the early universe contains a wealth of information about the state of the intergalactic medium during the first Gyr of cosmic history from which properties of the first stars and galaxies can be inferred. Modern interferometers like HERA (http://reionization.org/), LoFAR (https://www.mpifr-bonn.mpg.de/en/lofar), and the MWA (http://www.mwatelescope.org/), have been designed to observe with many antennas simultaneously to maximize their sensitivity to the 21-cm signal. These experiments have shown that detecting this signal is rife with difficulty (Abdurashidova et al., 2022; Mertens et al., 2020; Trott et al., 2020), primarily due to the presence of bright, contaminating sources between us and the cosmological signal, referred to as "foregrounds." Because these foregrounds are several orders of magnitude brighter than the 21-cm signal we wish to detect, advanced data analysis tools are needed to extract accurate estimates of the faint, 21-cm signal.

Summary

BayesEoR is a GPU-accelerated, Python-based implementation of a Bayesian framework designed to jointly model the 21-cm and foreground signals and forward model the instrument with which these signals are observed. Using these combined techniques, we can overcome the aforementioned difficulties associated with extracting a faint, background signal in the presence of bright foregrounds. BayesEoR enables one to sample directly from the marginal posterior distribution of the power spectrum of the underlying 21-cm signal in interferometric data, enabling recovery of statistically robust and unbiased[1] estimates of the 21-cm power spectrum and its uncertainties (Burba et al., 2023; Sims et al., 2016, 2019; Sims & Pober, 2019). The outputs of an analysis using the test dataset and plotting code provided with BayesEoR can be found in Figure 1.

[1] Recovery of unbiased estimates of the 21-cm power spectrum requires that the field-of-view of the foreground model encompasses the region of sky from which instrument-weighted foregrounds contribute significantly to the observed data (Burba et al., 2023).

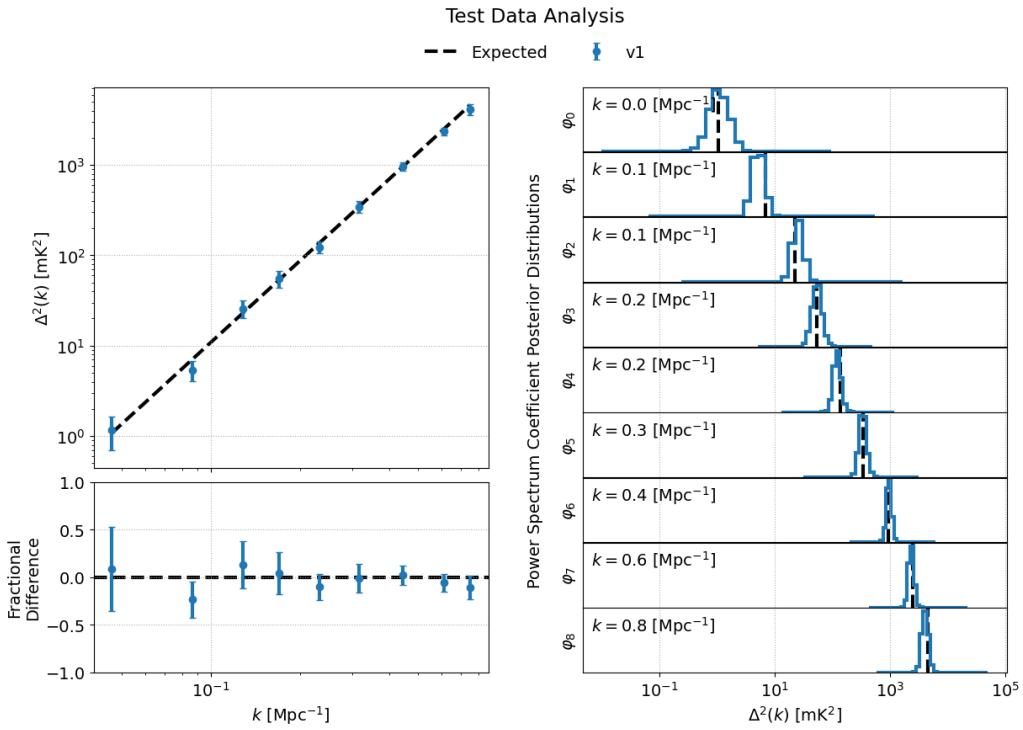

Figure 1: Example outputs from a `BayesEoR` analysis of the provided test dataset with a known power spectrum. The top left subplot shows the inferred power spectrum estimates in blue and the expected power spectrum as the black, dashed line. The bottom left subplot shows the fractional difference between the recovered and expected power spectra. The right subplots show the posterior distribution of each power spectrum coefficient in blue with the expected power spectrum amplitude as the black, vertical, dashed lines.

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