Full Data Analysis Pipeline for Low Radio Frequency Measurements of the Dark Ages and Cosmic Dawn

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To observationally constrain model parameters describing the sky-averaged 21-cm signal produced by a hyperfine transition of neutral hydrogen at the end of the Dark Ages and during Cosmic Dawn and the Epoch of Reionization (EoR), we are developing a complete data analysis pipeline that can be applied to measurements from both existing ground-based and planned space-based telescopes. In particular, this work is key in the development of a SmallSat mission concept that has recently been funded by NASA for a study, the Dark Ages Polarimeter PathfindER (DAPPER), which measures global emission at low frequencies from lunar orbit. Such a pristine environment is required to avoid ionospheric effects and minimize radio frequency interference from Earth.

Using our pattern recognition plus information criteria code, pylinex, which is publicly available, we extract the global 21-cm signal from bright beam-weighted foregrounds and instrument systematics, independently of any given physical model. In addition, we demonstrated that an experimental design utilizing polarization data significantly increases our ability to separate the signal from large foregrounds. The incorporation of this novel technique into our likelihood analysis helps us to discriminate between polarized foregrounds, as induced by the rotation of their anisotropies observed by an antenna with a wide beam, and the isotropic, unpolarized 21-cm signal. This powerful polarization technique is being employed on the ground by the Cosmic Twilight Polarimeter and is to be implemented in space by DAPPER. We showed the success of this first step of the pipeline by generating realistically simulated data from which we recover inputted signals.

For the second step of the pipeline, we employ a multidimensional interpolation technique using a Delaunay triangulation of training set inputs that translates the model-independent signal extracted by pylinex into the physical parameter space of the chosen model. We are then able to use this result as an initial guess for the final step of the pipeline, a Markov Chain Monte Carlo (MCMC) sampling of the posterior probability density distribution of the selected space. Using a data-based MCMC starting point to facilitate an efficient search, our pipeline circumvents the current lack of knowledge on the underlying astrophysics of the first stars and black holes that imprinted the 21-cm signal, as well as of any exotic physics modifying it, such as scattering of baryons with dark matter particles, as suggested to explain the recent results from the Experiment to Detect the Global EoR Signature. Importantly, provided different signal training sets such as for non-standard cooling scenarios, our pipeline can statistically determine whether each set matches the data.