Calibration Requirements for Detecting the 21 cm Epoch of Reionization Power Spectrum and Implications for the SKA

N. Barry*[1], B. Hazelton[2,1], I. Sullivan[3], M. F. Morales[1], and J. C. Pober[4]

[1] University of Washington, Department of Physics
[2] University of Washington, eScience Institute
[3] University of Washington, Department of Astronomy
[4] Brown University, Department of Physics

21 cm Epoch of Reionization observations promise to transform our understanding of galaxy formation, but these observations are impossible without unprecedented levels of instrument calibration. We present end-to-end simulations of a full EoR power spectrum analysis including all of the major components of a real data processing pipeline: models of astrophysical foregrounds and EoR signal, frequency-dependent instrument effects, sky-based antenna calibration, and the full PS analysis. Our simulation techniques explore and validate sky-based calibration schemes, but the basic principles of our pipeline can be used to validate other calibration schemes.

This study reveals that a traditional sky-based calibration with independent parameters for each frequency and antenna can only be implemented in EoR measurement analyses if the calibration model is unrealistically accurate. For realistic levels of catalogue completeness, the calibration introduces contamination two orders of magnitude larger than the EoR signal in otherwise foreground-free power spectrum modes, precluding a PS measurement.

We explore the origin of this contamination and potential mitigation techniques for sky-based calibration. We show that there is a strong joint constraint on the precision of the calibration catalogue and the inherent spectral smoothness of antennae, resulting in a recommendation that EoR instruments aim to have no spectral features larger than 1 part in $\sim 10^5$ on scales faster than $\sim$8 MHz (125 ns). Otherwise, over 80% of the flux seen by the instrument must be modeled perfectly in perfectly stable conditions across multiple LSTs to reach the necessary calibration precision. This has significant implications for the instrumental design of the SKA and other future EoR observatories.