FUNDAMENTAL LIMITATIONS ON THE CALIBRATION OF REDUNDANT 21-CM COSMOLOGY INSTRUMENTS AND IMPLICATIONS FOR HERA AND THE SKA

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Precise instrument calibration is critical to the success of 21-cm Cosmology experiments. In recent years, redundant calibration has emerged as a potential solution to calibration errors associated with an incomplete sky model. We show that redundant calibration, like traditional sky-based calibration, is susceptible to errors from sky model incompleteness. These errors contaminate the Epoch of Reionization (EoR) signal and can preclude a measurement.

Astrophysical foregrounds are 4-5 orders-of-magnitude brighter than the cosmological signal, but because they are spectrally smooth they are in principle separable. Unmitigated calibration errors can couple bright foreground emission to higher power spectrum modes, making an EoR signal detection impossible. Barry et al. 2016 identifies one class of systematic errors that emerge from calibrating to an incomplete sky model (N. Barry et al., Mon. Not. R. Astron. Soc., 461, 2016). Missing sources in the sky model, along with their associated point spread functions, introduce chromatic calibration errors that contaminate the power spectrum modes sensitive to the EoR.

Barry et al. 2016 explored these errors in the context of sky calibration, but it has been unclear if they also affect the calibration of redundant arrays. We present a mathematical framework to show that redundant calibration is vulnerable to errors from sky model incompleteness that emerge in the “absolute calibration” step, in which degenerate calibration parameters are calculated from a sky model. Using end-to-end power spectrum simulations with idealized radio arrays and sky models, we show that these errors can prevent an EoR detection even in the limit of perfect array redundancy and no thermal noise. Finally, we suggest error mitigation strategies with implications for the Hydrogen Epoch of Reionization Array (HERA) and the Square Kilometre Array (SKA).