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Optimizing Aperture Arrays for Bright Foreground Removal: HERA and Beyond

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1 Abstract

The Hydrogen Epoch of Reionization Array (HERA) uses the unique properties of the 21 cm line of neutral hydrogen to probe the Epoch of Reionization (EoR) and the preceding heating epoch. These epochs, roughly 0.3 to 1 Gyr after the Big Bang, represent the frontier in studies of cosmic structure formation, during which emission from the first stars and black holes heated and reionized the Universe. By directly observing fluctuations in the large scale structure of 21 cm emission as it evolves with time, HERA provides an incisive and unique tool to study the cosmological and astrophysical processes that governed the formation of the first galaxies and black holes, and how they heated and ionized the primordial intergalactic medium (IGM).

With three staggered sectors in its 320-dish core, 30 outrigger antennas for enhanced imaging, and wide-bandwidth feeds sensitive from 50 to 250 MHz, HERA's design is driven by the need to remove bright foregrounds to make high-significance power-spectral measurements from redshifts $5 \leq z \leq 27$. In particular, HERA has been optimized to deliver an instrumental response that preserves the spectral smoothness that distinguishes foregrounds from the cosmological 21 cm signal. The compact, staggered core of HERA's antenna configuration furnishes redundant measurements sampled on a sub-aperture scale. This allows one to use partial coherence to instantaneously solve for degrees of freedom in the HERA beam within a redundant calibration framework and provides the dense multiply sampled uv-coverage needed to develop precise foreground models. HERA's dense grid also provides numerous interferometric baselines that sample identical angular modes at different frequencies. Using redundancy along the frequency axis provides a natural framework for determining the spectral evolution of an instrument and for constraining the amount of spectral structure that can be absorbed into a calibration model.

In this talk, we investigate key trade-offs in the design of large aperture array telescopes that can impact the foreground mitigation strategies available for accessing the cosmological 21 cm signal. We offer some lessons garnered from HERA and other current-generation experiments, and also discuss some forward-looking strategies that might be incorporated into the designs of next-generation instruments seeking to directly image the IGM during reionization.