Scaled Antennas for Ascertaining the Radio Index (SAFARI) for low-frequency cosmology

In contrast to large interferometric arrays, by using a single broadband antenna or a small compact array, sky-averaged (or global) 21-cm experiments offer a complementary and experimentally simpler means to measure the redshifted cosmological neutral hydrogen spin-flip 21-cm transition for studying the thermal and ionization evolution of the intergalactic medium (IGM) in the early Universe.

Two main challenges in separating the weak cosmological 21-cm signal from Galactic and extragalactic synchrotron emission are the limited knowledge of the absolute foreground sky brightness at low frequencies along with the frequency-dependent antenna beam patterns, or beam chromaticity. Although the former is typically parametrized by a spectrally smooth power law function, it is highly uncertain due to incomplete spectral and spatial coverage by existing sky survey maps. Meanwhile, intrinsic beam chromaticity of a broadband antenna distorts the foreground spectrum and further complicates the differentiation of the underlying global 21-cm spectrum. There is no accurate means to characterize the antenna beam pattern to the required level at those frequencies besides limited success from joint constraint of antenna range measurement and computational electromagnetics (CEM) simulation.

As an attempt to circumvent these two obstacles, we propose a differential measurement approach which utilizes a narrowband and high gain antenna along with its scaled duplicates at different resonant frequencies across the 50-150 MHz band. Each antenna copy consists of components scaled proportionally to the corresponding wavelength. Consequently, an identical beam pattern is obtained for each of the scaled subbands thus suppressing the beam chromaticity. Although the radio spectral index varies as the sky drifts overhead, it is a constant value for a given Local Sidereal Time (LST) between days. By empirically determining the spectral index between brightness temperature measurements of any two adjacent subbands at the same LST over the band, any measurable deviations in the spectral index will suggest the presence of additional signal components other than spectrally smooth foreground. Such a relative measurement of the sky temperature between subbands forgoes needing absolute flux calibration nor modeling of the foreground.

I will present of the general formalism of this spectral index differential measurement and how that can help constraining any potential global 21-cm signal. The conceptual instrument design, instrumental systematic error analysis, and deployment strategy for the SAFARI prototype will also be highlighted.