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Antenna Design for MIST and Its Characterization for Different Soil Parameters

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Extended Abstract

Mapper of the IGM Spin Temperature (MIST) is an experiment to measure the 21-cm global signal from the Cosmic Dawn (35>z>6), when the first stars in the universe ignited. Due to the high redshift of the 21-cm signal, it is expected to be measured in the frequency range 40-200 MHz. A recent effort made the first detection of the signal in the sky-averaged spectrum as a dip centered at 78 MHz, with an amplitude of ∼500 mK [1]. The experiment is limited entirely by systematics, and therefore relies on careful antenna design and calibration procedures. MIST plans to use a single-dipole blade antenna placed directly above soil without a metal ground plane, with stationary zenith pointing. The operating frequency range of the experiment falls within the VHF band, which motivates the remote observing locations to avoid RF contamination: the Atacama Desert in Chile, and the McGill Arctic Research Station (MARS), at a latitude of 79.5 degrees north.

I will present the design of the MIST antenna, which was developed and optimized with electromagnetic (EM) simulations using WIPL-D and FEKO. In these simulations, we varied the blade antenna dimensions, and analyzed the antenna reflection coefficient (Γ), and the resulting two-dimensional beam pattern as a function of frequency. Γ minimization across frequency is important to obtain a measured temperature that approaches the temperature of the sky [2].

If the antenna beam pattern is not smooth, it couples spatial structures in the sky into spectral features. These induced spectral signals potentially mimic or mask the low-amplitude millikelvin-scale 21-cm global signal. To reduce such effects, we will use an antenna over soil, instead of using a ground plane. The shape of Γ and beam spectral smoothness vary when the antenna is placed over soils with different conductivities, and relative permittivities. I will discuss simulations of the blade antenna with varying dimensions and over different types of soil, and interplay between these parameters and antenna performance. These simulations informed an optimized design that was subsequently constructed as a prototype. Measuring in-situ soil parameters is critical to precisely connect simulations with observations. I will discuss methods to perform soil characterization using four-probes and time domain reflectometry, and their advantages and disadvantages to the applications in cosmology experiments.

References

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[2] Alan EE Rogers, and Judd D. Bowman. "Absolute calibration of a wideband antenna and spectrometer for accurate sky noise temperature measurements." Radio Science 47.6, 2012.