

A Designer's Guide to Lunar Far-Side Interferometer Array: Power Spectrum Measurement and Cosmological Information in the Dark Ages

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The 21-cm signal from the cosmic Dark Ages is a powerful probe of cosmology and inflation, but its science potential depends critically on the design of the lunar far-side interferometer that will observe it. We derive closed-form relations connecting the array design to the two goals this epoch offers: measuring a chosen small scale, and extracting the largest possible cosmological information from the survey as a whole. These relations provide a quantitative prescription of resources required to reach a stated detection threshold at a tunable scale of interest and show that the optimal configuration for the power spectrum at that scale is to split the collecting area among multiple stations. For fixed resources, splitting a single array into two or three stations can raise S/N at $k_{\perp} = 1 \text{ Mpc}^{-1}$ by factors of about 10 and 16, reaching two orders of magnitude at smaller scales. For the purpose of cosmological parameter constraints, we derive where the cosmological information accessible to a lunar array resides, in redshift and in transverse wavenumber, and find that thermal noise erodes the often-quoted 10^{12} modes to an effective budget of order 10^4 , half of which accumulates below $z \approx 36$. As a demonstration, we forecast $\sigma(\alpha_s) = 0.034$ for the running of the spectral index assuming a near-term array configuration, illustrating both the prospects and the limitations implied by these relations.

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