# HERA: Illuminating Our Early Universe

## Overview

Hydrogen Epoch of Reionization Arrays (HERA) is a roadmap for characterizing cosmic reionization — the epoch when the first luminous sources ionized the bulk of the hydrogen in the Universe — via redshifted 21 cm hyperfine emission from neutral hydrogen. Building on the successes of first-generation HERA instruments (PAPER, MWA, LEDA, MITEoR, and EDGES), we propose to a staged build-out to the next phase of HERA: a 568-element radio interferometric array of 14-m parabolic dishes observing between 50 and 225 MHz. This instrument brings to bear both experimentally validated foreground suppression techniques and the collecting area required to open new windows into our early universe. New measurements with HERA-568 will be capable of determining ionization fraction versus redshift over the bulk of reionization, constraining the size of ionization bubbles to help determine the properties of first galaxies, and directly imaging larger structures during reionization. HERA will also begin to explore the 'dark ages' before reionization when a wealth of astrophysical and cosmological processes impacted the temperature of the intergalactic medium.

## Intellectual Merit

The 21 cm hyperfine transition is widely recognized as potentially the most powerful probe of large-scale structure from the dark ages through reionization. The evolution of this signal from the neutral intergalactic medium depends on myriad physical processes; the relative importance of these competing effects is sensitive to, among other things, the expansion of the universe, the ignition of the first stars and galaxies, the formation of the first massive black holes, and the relative velocity of baryonic matter and dark-matter halos. Detecting this signal will have an impact comparable to the discovery of the cosmic microwave background, and study of the three-dimensional evolution of large-scale structure via the 21 cm line has the potential to become 'the richest of all cosmological data sets'.

Given these complexities, current constraints on cosmic reionization remain rudimentary. When did it occur, and over what timescale? What objects dominated the radiation field? How were the objects distributed? Did the first generation of stars & galaxies enhance or suppress the formation of subsequent stars & galaxies in the original halo and smaller nearby halos? Without new constraints, further progress on theoretical modeling of first galaxy formation and cosmic reionization remains problematic. The proposed HERA program provides a powerful new tool for producing observational constraints on reionization, and potentially on large scale structure evolution during the dark ages. The new windows that HERA opens into our early universe have the capability to transform our scientific understanding of our cosmic dawn at the complex intersection of cosmology and astrophysics. HERA represents a major step toward unlocking the widely recognized scientific potential of 21 cm cosmology.

## Broader Impacts

This proposal addresses the loss of talented astronomers involved in instrumentation by addressing a gap in preparation between the undergraduate and graduate level of involvement. Young graduate students will be involved in the the development, deployment, commissioning, and characterization of all stages of the HERA instrument. This proposal also funds an intern position at UC Berkeley's RAL, offered each year to a person to gain practical experience developing the HERA instrument, with the goal of acquiring the skills required for pursuing graduate research in instrumentation.

Another important HERA activity, and one of the most personally fulfilling, is the cooperative education of minority students from South Africa in STEM fields. We have established formal collaborations with faculty at South African universities to engage doctoral students in all aspects of the HERA project, from field engineering to rigorous data analysis. We also plan to establish student exchanges to draw minority students from South Africa into many of HERA's funded graduate positions. Involvement in the program will help ensure that these students are well-positioned for future success.

Finally, HERA will disseminate various data products to the community, including wide-field sky maps, high-speed continuum images, deep foreground-subtracted images, and full-sensitivity data products, for enabling additional science and for cross-correlation analyses with other large-scale probes of the early universe.