HERA: Illuminating Our Early Universe

Overview

As endorsed in the recent astronomy decadal survey, 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. Following on the successes of first-generation HERA instruments (PAPER, MWA, LEDA, MITEoR, and EDGES), we propose to build the next phase of HERA using 14-m fixed-pointing parabolic dishes, deployed in stages of 127, 331, and 568 elements, observing from 50 to 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.

Each stage of HERA delivers new science capabilities: HERA 127 will be capable of determining ionization fraction versus redshift over the bulk of reionization, HERA 331 will constrain the size of ionization bubbles to help determine the properties of first galaxies, and HERA 568 directly image 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'.

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? What were the most important feedback mechanisms in the transition from the first stars to first galaxies, and how did they affect these populations? Without new constraints, further progress on theoretical modeling of first galaxy formation and cosmic reionization remains problematic. HERA provides the key measurements that are needed to advance our understanding of early galaxy formation and cosmic reionization. The proposed HERA program provides a powerful new capabilities for producing observational constraints on reionization and 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 the complex interaction of cosmology and astrophysics during our cosmic dawn. HERA represents a major step toward unlocking the widely recognized scientific potential of 21-cm cosmology.

Broader Impacts

The HERA program will train new instrumentalists at the graduate and undergraduate levels, increase the diversity of US graduate programs by engaging South African students and preparing them for admission to US degree programs, and make our major data products available publicly. HERA will involve graduate students in all stages of HERA development and observation. We also fund an undergraduate specialist position at UC Berkeley's RAL, offered annually, mentoring the individual in the skills required to pursue graduate research in instrumentation.

Another important HERA activity is the cooperative education of under-served students from South Africa in STEM fields. We have established formal collaborations with faculty at South African universities to engage doctoral students in the HERA project. We will establish student exchanges to enhance the diversity of US graduate programs by preparing South African students for admission to US degree programs. 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, These enable auxiliary science, including cross-correlation analyses with other complementary large-scale probes of reionization.