COLLABORATIVE RESEARCH: The BAO Broadband And Broad-beam (BAOBAB) Array

We propose to develop a dedicated instrument for characterizing baryon acoustic oscillations (BAO) via intensity mapping of HI 21cm emission in the redshift range $z = 0.8$–2.5 (400–800 MHz). BAO features in large-scale matter distribution have recently drawn attention as a standard ruler by which the expansion history of the universe can be directly measured. Measuring the BAO wiggles at several redshifts yields measurements of the Hubble parameter, $H(z)$, and the angular diameter distance, $d_A(z)$, that constrain properties of the dark energy that dominates the cosmic energy content at $z = 0$, and is the current leading theory for the accelerating expansion of the universe.

Rather than target individual objects, 21cm intensity mapping measures fluctuations in neutral hydrogen emission on large scales, with two dimensions corresponding to angles on the sky, and the third line-of-sight dimension arising from the differential redshifting of 21cm line emission as a function of distance. After reionization, the power spectrum of 21cm fluctuations is expected to be a biased tracer of the matter power-spectrum, since the remaining neutral hydrogen resides in high-density, self-shielded regions in galaxies and other collapsed halos. As a result, 21cm intensity mapping presents a promising complement to spectroscopic galaxy surveys for BAO science; a 21cm intensity mapping experiment can probe redshifts $0.5 < z < 2.5$ with roughly uniform sensitivity, without complications arising from sky emission lines in the optical/near-infrared.

Many of the instrumental approaches, foreground mitigation strategies, and data analysis techniques developed for studying reionization with the 21cm line at $z \sim 10$ apply directly to the study of BAO at $z \sim 1$. A new BAO instrument, drawing on the considerable investments in low-frequency radio astronomy made in the past decade, can inexpensively leapfrog existing efforts to become a global leader in this area. In this vein, we propose to develop the BAO Broadband and Broad-beam (BAOBAB) array by leveraging the techniques, instrumentation, and infrastructure of the Precision Array to Probe the Epoch of Reionization (PAPER) and the Murchison Widefield Array (MWA). BAOBAB will begin in the first year with the deployment of a 25-tile array at the NRAO site near Green Bank, WV, based on an existing tile design using a scaled version of the PAPER sleeved dipole, with associated analog electronics. In the second year, BAOBAB's front-end amplifier will be improved to reduce the receiver noise that dominates the system temperature. Existing tiles will be retrofitted, and an additional 24 tiles will be deployed, for a total of 49. BAOBAB's correlator will combine decommissioned FPGA hardware from PAPER with new commercial GPU processors, following the scalable FPGA/GPU correlator design pioneered by PAPER.

The primary goals of these activities will be: 1) to develop an analog system that meets the specifications for foreground removal, sensitivity, and scalability to larger array sizes, 2) to characterize foregrounds to the 21cm BAO power spectrum, and 3) to obtain a $\geq 5\sigma$ measurement of the 21cm power spectrum from which the neutral hydrogen fraction at $z \sim 1$ can be derived. These accomplishments herald next-generation efforts to measure BAO features versus redshift with an array four-times the size. The broader impacts of this research include the development of technology and software shared with other astronomy efforts, the installation of small, 8-element interferometers at each of the three host institutions for education and outreach initiatives, and the establishment of a collaboration spanning multiple 21cm cosmology groups that promotes the HERA roadmap that was favored in the A2010 Decadal Survey. The design of BAOBAB's wide-bandwidth digital correlator will be shared with external research groups in the US, South Africa, Australia, and India via the CASPER collaboration. Analysis software and techniques developed for BAOBAB will be shared with PAPER and MWA. BAOBAB will have a strong educational emphasis, with fundamental contributions being made by graduate students in instrumentation, software development and scientific analysis. These efforts will be valuable for training the next generation of scientists who will lead the next stages of 21cm BAO and reionization experiments.