Architecture, Calibration, and Early Results for PAPER

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The Precision Array for Probing the Epoch of Reionization (PAPER) is an experiment designed to detect 21 cm emission between redshifts 7 and 12 from gas excited by the first era of star formation. Our approach is a series of array deployments of increasing scale with thorough data analysis at each stage. We present results from a 4-antenna deployment in western Australia in July 2007, and from a current 16-antenna deployment in Green Bank, USA, and discuss the upcoming 32-antenna deployment to western Australia in Fall 2008. Increasing levels of interference removal, calibration, modeling, and mapping are being achieved using a general-purpose, open-source data reduction package we are developing for this project.

Each component of our experiment is being designed with attention to enabling the large multi-variable calibration fit that must occur in nearly real time to compensate for a fluctuating ionosphere and temperature-dependent gains. The goal of this calibration is to model and remove celestial point sources with sufficient accuracy such that confusion noise can be supressed below the expected ~ 5 mK threshold at which fluctuations in the redshifted 21 cm background are expected to be visible. We have given careful attention to designing an antenna and receiver system that are smooth with frequency to facilitate the removal of the galactic synchrotron foreground and confusion noise, both of which are expected to be smooth compared to the 21 cm signal. Our antennas and platforms are easily movable, allowing us to explore various antenna configurations that facilitate calibration while trying to maximize array sensitivity to the angular scales at which the 21 cm background peaks compared to interfering foregrounds. Our ability to reconfigure our array allows us to explore both visibility-domain and image-domain paths for detecting the Epoch of Reionization.

The incremental development of the PAPER project is enabled in part by a flexible correlator architecture based on Field Programmable Gate Arrays (FPGAs) and packetized interconnect developed in collaboration with the Center for Astronomy Signal Processing and Electronics Research (CASPER). This architecture uses asynchronous, packetized data transmission to allow the number of antennas in an array to be scaled without changing the way data is processed in the system. Having a fully functional correlator at each stage of development has allowed us to address radio interference, calibration, and modelling issues as they appear in data, and to begin development of the data processing pipeline needed to achieve increasingly accurate models of our instrument and the radio sky. This processing pipeline is being written as a general-purpose, open-source toolkit accessible via the Python programming language, and is designed from the ground up to address the problems and advantages of low-frequency arrays with large fields-of-view, wide bandwidths, and many antennas.