PAPER: Portable Array to Probe the Epoch of Reionization

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In the early Universe the decoupling of hot, ionized matter from radiation at a redshift around 1000 is followed by combination of Hydrogen and trace amounts of other elements to their neutral states. Feeble density fluctuations exist as shown by structures imposed on the microwave background radiation. These fluctuations continue to collapse under gravity during a long, hundreds of millions of years, dark age in the evolution of the Universe. Ultimately the first objects – stars, stellar systems and massive black holes – form at redshifts around 20. The UV emission from these objects will excite the 'spin' temperature of the 21cm line in Hydrogen above the ambient kinetic and radiation temperature such that the line will begin to appear in emission. This emission will continue for a given line of sight until full ionization occurs at the 'epoch of reionization'.

A number of authors, including Shaver et al. (1999 A&A), have discussed the amplitude and structure of this redshifted spectrum of Hydrogen, and how it might be detected. During the last 5 years many have written on this topic – theory, simulations and approaches to, and impediments to, detection. The reionization epoch is now bounded by the WMAP detection of linear polarization which is interpreted as evidence for partial ionization at a redshift around 15, and the Gunn-Peterson absorption troughs at redshifts in the range 6 to 6.5 that tell us the ionization becomes complete during this interval. The predicted signal amplitudes of the redshifted 21cm radiation is in the range of 1 to 10's of mK in this range of redshifts which correspond to radio frequencies from 190 MHz to 90 MHz. Angular scales above 10" are relevant. Several experimental approaches to detection of these faint HI emission signals are being pursued. Some groups seek to measure the global spectrum of the sky with steradian resolution. Others are looking for halos around first quasars. Several groups are pursuing spectral imaging with varying angular resolution. Foregrounds of galactic synchrotron, extragalactic point sources, galactic recombination lines and terrestrial interference all provide serious impediments to detection. A pioneering experiment by Bebbington (1986, MNRAS) placed a (not interesting) limit of 1200 mK on potential HI emission structures at 150 MHz.

In late August 2004 we launched PAPER-2: 2 broadband dipoles on a 200m baseline in Green Bank and linked with an FX correlator. The dipoles were designed for smooth dependences on angle and frequency to allow differential measurements at the high level of subtraction that will be essential to reach the mK level. The interim correlator used an FPGA spectrometer to generate 8 4-MHz channels of data that were passed to a computer for high resolution FX correlation in software. Basic operation was demonstrated including RFI assessment and baseline determination using Cygnus A.

In December 2004 we upgraded to PAPER-4, a 4-dipole array with minimum redundancy EW baseline configuration. The correlator was upgraded to a 50-MHz, 4-station design making use of a copy of the prototype correlator developed for the Allen Telescope Array (ATA). We are now exploring the system stability and developing wide-field imaging capability. A current goal is a full-northern sky synthesis with approximately 1-degree angular resolution.

By mid-2005 we will have 32-elements with full Stokes parameter and 100-MHz bandwidth sampling. The first generation ATA correlator will be replicated for this application. All elements will be on equal length cables, and allow us to repeat measurements of the sky with dithered, or even completely reconfigured, element locations. The array is highly portable and negotiations are underway to transport PAPER-32 to a low human interference environment such as Western Australia.