HERA

1. Scientific Justification

Our proposal is directed toward the science of cosmic reionization–the rapid ionization of the majority of the hydrogen in the universe by the light of the first stars and supermassive black holes (Furlanetto et al. 2006). The HERA program was the highest ranked of the Decadal Survey RMS Panel scientific recommendations (A2010 Panel Reports).

1.1. *Our Understanding of Cosmic Reionization*

Modern cosmology predicts the existence of a mostly neutral IGM lasting from cosmic recombination until the first luminous objects ionized it between 300 and 800Myrs after the Big Bang. Redshifted emission from the 21cm hyperfine transition of neutral hydrogen provides a unique tracer of the primordial IGM. Variations in this signal versus redshift and direction could be reconstructed into a three-dimensional map of the evolution of cosmic structure (Furlanetto et al. 2006). The direct observation of the neutral IGM via this signal would be an achievement comparable with the discovery of the Cosmic Microwave Background (CMB).

Recent observations of Gunn-Peterson absorption by the IGM toward the most distant quasars and the large-scale polarization of the CMB indicate that reionization was a complex process starting perhaps as early as $z \approx 14$, with the last vestiges of the the neutral IGM being etched-away by $z \approx 6$ (Fan et al. 2006; Page et al. 2007; Becker et al. 2001). Unfortunately, both of these ground-breaking results are limited in diagnostic capabilities: the Gunn-Peterson effect saturates at low neutral fractions, and the CMB polarization only provides an integral measure of the Thompson optical depth back to recombination.

The HI 21 cm signal depends on a number of factors such as the evolution of the matter density power spectrum, the efficiency of ionizing photon production in early galaxies, the effect of X-ray, shock, and Lyα heating on the thermal balance between the CMB and the kinetic and spin temperatures of gas in the IGM, and the feedback of this heating on star formation. Hence, study of the evolution of the neutral IGM provides a rich physical data set that constrains the nature and distribution of the first luminous sources, early large scale structure formation, and radiative processes in the early Universe (Morales et al. 2010). It comes with no surprise that the Decadal Survey Report called out the probing of this last unexplored vista of cosmic evolution as one of the "primary areas with extraordinary discovery potential" in astrophysics in the next decade (A2010).

Over the past decade, cosmologists have focused extensively on modeling of reionization. Fig. 1 shows a recent simulation of HI 21 cm emission during reionization (McQuinn 2010, unpublished) that is typical of the growing sophistication of such models (Santos et al. 2010; Mesinger et al. 2010; Zahn et al. 2010; Wyithe et al. 2004), and is unique for spanning much of PAPER's redshift and spatial coverage. Three-dimensional tomographic imaging of how temperature fluctuations grow and are erased by ionization will require a collecting area comparable to a full Square Kilometer Array (SKA). However, detecting the fluctuating 21 cm signal from the IGM prior to a full SKA is still possible statistically through power spectrum analysis, in direct analogy to the statistical discovery of CMB fluctuations by COBE.

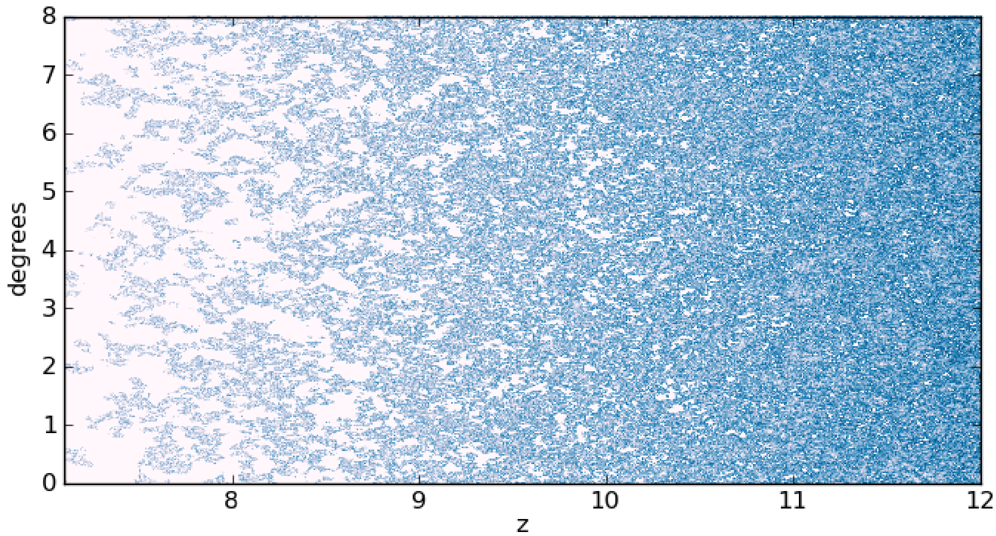

Fig. 1.— Shown above is a large-scale simulation of 21 cm brightness temperature of HI, accounting for evolution in ionization fraction (McQuinn 2010). At high redshift ($z = 12$; 106MHz), brightness temperature tracks gas density. As density fluctuations grow, UV photon production outpaces recombination, and regions become ionized (white). At the end of the era ($z = 7$; 177MHz) only the rarest regions have any remaining neutral hydrogen. Large simulation volumes and continuous redshift coverage from $z = 6$ to $z = 12$ are key elements of simulations relevant to PAPER.

1.2. *HERA Objectives*

1.3. *In the Context of the HERA Road Map*

1.4. *Content of the Proposal*

2. The HERA Instrument and Signal Flow

Figure **??** shows the overall layout of antennas and distribution, which is obviously a regular square grid. This allows tensioning of the elements against one another to minimize cost/performance. Outliers are possible, but the per element cost will be higher.

3. Reionization Science

3.1. *Power Spectrum Measurements*

3.2. *Foreground Characterization*

4. Broader Impact of Our Activities

4.1. *Instrument Development and Analysis Techniques*

4.2. *Student Training*

4.3. *Benefits to the Community*

4.4. *Preparations for HERA II*

Parameter	Value	Units	Description
N	576		Number of Antennas
d	14	m	Antenna Diameter
f/d	0.32		Focal Length (fractional)
$\Omega_{\rm P}$	0.026	sr	Field of View (power)
$\Omega_{\rm PP}$	0.013	sr	Field of View (power^2)
$\Omega_{\rm eff}$	0.052	sr	Field of View (sensitivity)
$B_{\rm samp}$	0–250	MHz	Sampled Frequency Range
$B_{\rm corr}$	100	MHz	Correlated Bandwidth
Config.	24 × 24		Square Grid Antenna Configuration
f/f_0	$1.5 \cdot 10^5$		Redundancy Metric (Parsons et al. 2012a)
A	0.09	km^2	Total Collecting Area
θ	15	arcmin	Angular Resolution (150 MHz)
$b_{\rm max}$	500	m	Maximum Baseline
$T_{\rm sys}$	500	K	System Temperature
$t_{\rm obs}$	120	days	Observing Time
$t_{\rm day}$	6	hrs	Observing Time Per Day
$\Delta^2_{\rm N}$	1.6	mK^2	Expected Noise Level ($k = 0.2h$ Mpc^{-1})
SNR$_{21}$	11.7σ		Expected Detection Significance (Lidz et al. 2008, $x_i = 0.5$, 150 MHz)