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Precision measurement challenges of 21~cm Cosmology

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Measurements of the all-ky averaged radio background at long wavelengths has received a great deal of attention in observational cosmology over past decade. This is due to the fact that the very first history of the cosmological evolution of the Universe is written in the spectral appearance of this radio continuum. Following cosmological recombination, interaction between the Cosmic Microwave Background (CMB) and the primordial neutral hydrogen via 21 cm spin flip radiation (referred to as cosmological HI signal hereafter) deviated the CMB spectrum from Planckian form. The spectral deviations was influenced by adiabatic expansion of the Universe during the ``Dark Ages'', heating of the gas by the sources of first light and subsequent ionization process during the ``Cosmic Dawn'' and the ``Epoch of Reionization''. Cosmological expansion and the consequent redshift of the radiation resulted in movement of this spectral fluctuations between 20-200~MHz, a detection of which is the key motivation today for any radio background measurement. At these frequencies, however, the CMB constitute only a small fraction of the total cosmic radio background. Bulk of the radiation is contributed collectively by the galactic and extragalactic radio sources that is at least 5 orders of magnitude brighter than the cosmological HI signal. Interaction of the sky signal with the chromatic telescope response, observation environment and ionospheric modulation introduces further distortion in sky signal. Perhaps the most challenging radio astronomy observation in current epoch is the detection of this cosmological HI signal by precision radio background measurements. A sober comparison would be the precision measurement of the CMB spectrum by FIRAS instrument on COBE satellite. FIRAS made a differential measurement of the CMB spectrum and an onboard blackbody source from the sky to determine the CMB spectrum with an rms deviation from a Planck curve 1:10^5. This was a space based experiment observing a thermal sky spectrum by comparison with a thermal load in the wavelength range of 0.5 to 5mm where radio frequency interference is negligible. The cosmological HI signal which is of non-thermal origin is to be detected against a non-thermal background which is 10000 times stronger than the cosmological signal in the frequency range of 20 to 200~MHz where radio frequency interferences could be 10000 times stronger than the sky power and ionospheric absorption reduces the signal amplitude.

In this paper, we present a summary of the most stringent technological challenges faced by the experiments that are attempting to detect the cosmological HI signal and the design strategies that can beat such challenges.
We will compare the measurement strategies of a single element telescope, a radio interferometers and hybrid systems for detecting the cosmologcal HI signal. Finally, we will present the concept design of the ``Hydrogen Probe of the Epoch of REIONization'' (HYPERION) - an interferometer for precision measurements of the radio background at long wavelengths.