PROJECT DESCRIPTION - THE HYDROGEN PROBE OF THE EPOCH OF REIONIZATION (HYPERION) : AN INTERFEROMETER FOR PRECISION MEASUREMENTS OF THE RADIO BACKGROUND AT LONG WAVELENGTHS

The HYPERION is a radio interferometer to make a differential measurement of the sky monopole and a ground based thermal emitter between 50-120 MHz for detecting the spectral signatures of the redshifted 21 cm monopole (spatial average) from the primordial neutral hydrogen (HI spin flip radiation). The redshifted HI signal is a tracer of the evolution history of first stars, first

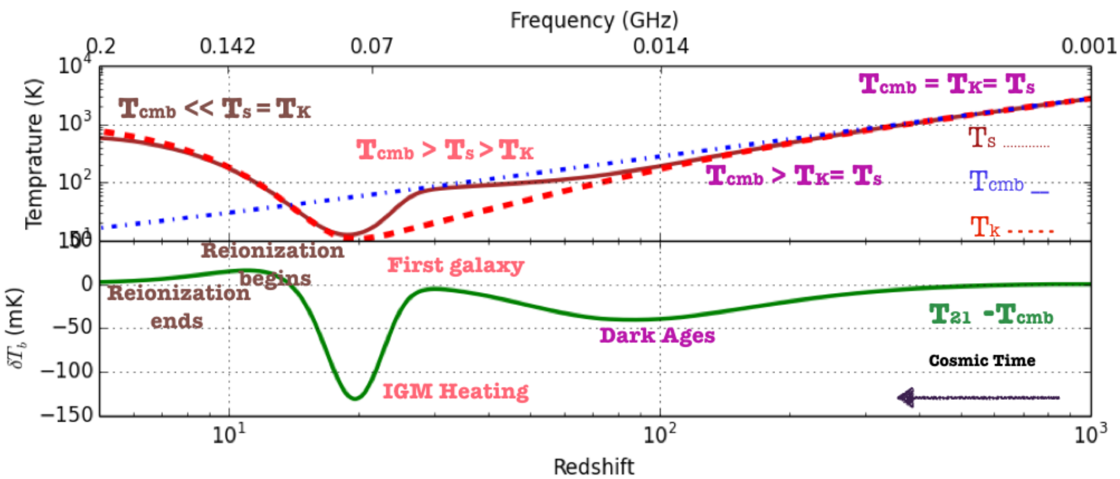

FIGURE 1. An example history of the evolution of the 21 cm monopole signal over cosmic time/redshift. The spin temperature T_s evolution with temperature T_{cmb} of the cosmic microwave background and kinetic temperature T_K of the gas was influenced by the astrophysical processed of the early Universe. This shaped the amplitude of the 21 cm signal over cosmic time (green).

blackholes and first galaxies and a direct detection will transform our understanding of the astrophysical processes in the early Universe. However, exploiting it requires solving one of the greatest challenges of observational cosmology - detecting an extremely weak signal of cosmological origin in presence of a radio continuum background which is at least five orders of magnitude brighter than the cosmological signal (figure 2).

The hardware requirement of monopole experiments is simple and a detection is possible using a linear dipole antenna over 24 hours integration [27]. But the system engineering and level of precision and control over systematic required is incredibly high for a successful detection using a total power radio telescope. First generation monopole experiments EDGES [2]), SARAS; [20], [22] , SCI-HI ([34]) used single element radiometers and produced a wealth of knowledge about the measurement technique and calibration strategy. The nonstandard effects that impact the possibility of a detection are studied in great detail. For example, angular structures of the foreground can be coupled into wideband measurements due to chromatic antenna beam and introduce spectral variation. Uncalibrated receiver or sky noise contribution at 0.1% level can result in residual spectral distortion which is few orders of magnitude brighter than the cosmological signal.

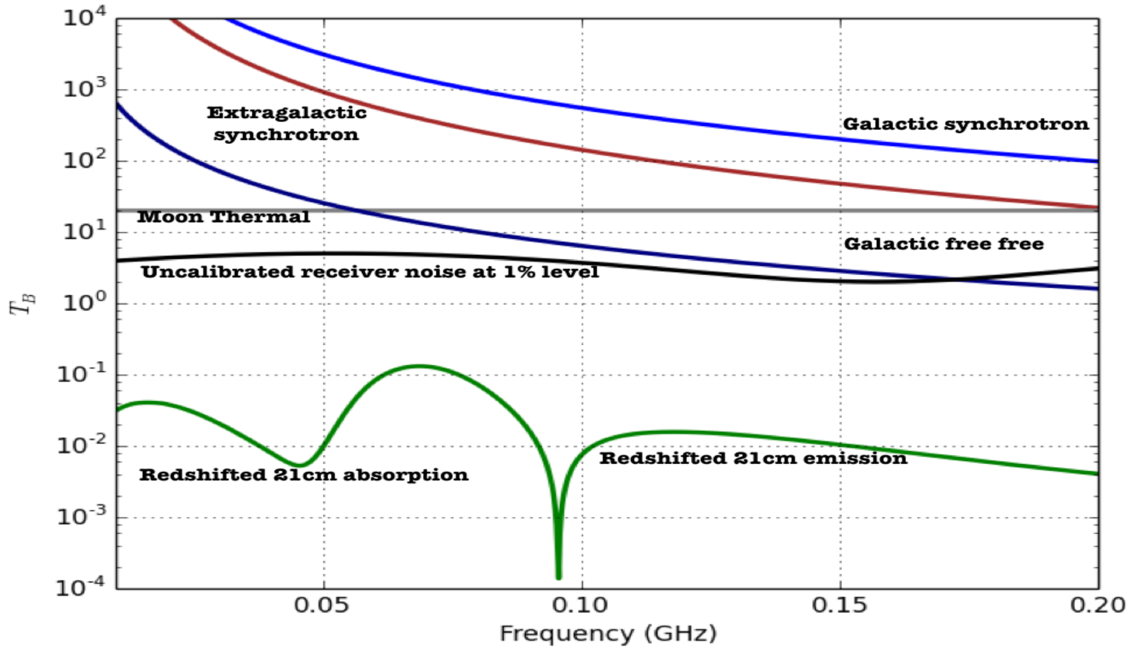

FIGURE 2. Dynamic range of signal detection for redshifted 21 cm monopole measurements - Galactic and extragalactic radio background at low radio frequencies (red, blue) are at least five orders of magnitude brighter than the redshifted 21 cm emission/absorption signal (green). Thermal emission of the moon as well as galactic free free emission results in additive contribution. At these frequencies, any residual sky/receiver noise that is uncalibrated at even 1% level can result in additive contamination that is at least five orders of magnitude larger than the cosmological 21 cm signal.

The instrument constitute of 10 short dipole elements that are ultrawideband and spatially smooth primary beam with nominal spectral variation.

FIGURE 3. HYPERION stage1: An interferometer with a baseline length $< \lambda/2$ with electromagnetic absorbers placed in between. The absorbers work in two ways. First, it reduces the

First generation monopole experiments EDGES [2]), SARAS; [20], [22] , SCI-HI ([34]) produced a wealth of knowledge about the measurement technique and calibration strategy. The nonstandard effects that impact the possibility of a detection is studied in great detail. For example, angular structures of the foreground can be coupled into wideband measurements due to chromatic antenna beam and introduce spectral variation. Preserving the monopole signal structure will require a beam variation as low as $0.04/MHz$ [16].

A pathfinder design of a frequency independent short dipole (SARAS antenna, 87.5 to 175 MHz) is presented in [26]. The scaled optimization of this is adopted for HYPERION array which is also frequency independent between 30 - 120 MHz. Uncalibrated receiver or sky noise contribution at 0.1% level can result in residual spectral distortion which is few orders of magnitude brighter than the cosmological signal. The complexity of calibrating monopole measurements for multiple reflections of the receiver and sky noise internal to the system is presented with unprecedented details in Patra et al.2013 [20], Patra et al.2015b [22] .[13] presented the precision calibration methodology developed for the EDGES high band receiver that reduces the system noise contribution to mili kelvin level where the cosmological signal can be detectable. Early observations of EDGES showed that the reionization of the cosmological neutral hydrogen occurred over $\Delta z > 0.06$ [2].

Although interferometers are immune to systematic effects, power spectrum measurements are dominated by the foreground at various spatial scales (figure **??**). The avoidance based foreground removal technique is documented in [17] (figure **??**). Multipath effects replicates the sky signal at the delays where foreground power spectrum is expected to be negligible. In a related series of 4 papers the effect of the element chromaticity of a HERA prototype element on the power spectrum measurements using single polarization is studied [30, 6, 7]. Effects of multiple reflections from the feed nearfield on the chromaticity of the single polarization of a prototype HERA element is measured using reflectometry technique in Patra et al.2017b [19]. [14] has shown the effects of polarization leakage on the power spectrum measurements due to beam asymmetry using the PAPER dipole antenna beam as an example. The proposed work investigate the effects of the polarization leakage due to multiple reflections in the reflector type antennas and its science impact. All these studies together constitute an exhaustive understanding of the mechanism by which foreground power can contaminate the cosmological 21 cm power spectrum measurement and help improve the design parameters, calibration strategy and data analysis pipeline.

Although response of interferometers to an isotropic signal integrates to zero when configured conventionally for radio imaging or spatial fluctuation measurements, it can be sensitive to the spatial monopole if a known spatial variation is introduced in the monopole background. (Ref: Harish LOFAR, Shaver et al). We use electromagnetic absorber baffles around individual interferometer elements. Absorber baffles are thermal emitters at ambient temperature that partially covers the antenna beams while creating a artificial discontinuity on the monopole sky and provide a reference temperature which is colder than the sky monopole at the observing frequencies 50-120 MHz. At these frequencies, the redshifted 21 cm signal is expected to have the spectral fluctuation that is cosmologically most significant and

HYPERION exploits the antenna element design of the "Shaped Antenna measurements of the background RAdio Spectrum" (SARAS;) with by further optimization for low frequency performance alongside a custom designed wideband analog receiver system and a digital spectrometer that is realized using the Smart Network ADC Processor (SNAP).

Our proposal is structured as follows: in §**??** we review the motivation, prospects, and methodology for measuring BAO with 21cm emission, in §2 we discuss our technical approach to designing the BAOBAB instrument, in §3 we describe the analysis initiatives that will be undertaken with BAOBAB data, and in §4 we discuss the broader impacts of our activities.

1. Intellectual Merit: Measuring the global 21 cm using interferometer

1.1. Leveraging 21cm Reionization Designs and Techniques.

2. From single dish to interferometer: Building on SARAS's Technical Legacy

2.1. Site and Array Configuration.

FIGURE 4. HYPERION stage1: An interferometer with a baseline length $< \lambda/2$ with electromagnetic absorbers placed in between. The absorbers work in two ways. First, it reduces the

TABLE 1. HYPERION: Instrument specification

Operating Bandwidth	30–120 MHz
Number of Elements	10
Gain per Element	1.76 dBi
Field-of-View per element	1.05 sr
Receiver Noise Temperature	150 K
Array Configuration	Reconfigurable: very short baseline ($< \lambda/2$) (Figure ??)
Frequency Resolution	87.9 kHz
Single spectrum Integration Time	4 s
Data Volume	45 GB per night

2.2. **Analog Signal Path.**

2.3. **Digital Correlator.**

2.4. **Data Storage/Computing.**

2.5. **Analysis Software.**

3. Data and Analysis Activities

4. Broader Impact of Our Activities

5. Prior Results

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