The HI 21-cm visibility signal and foreground simulations for the Ooty Wide Field Array(OWFA)

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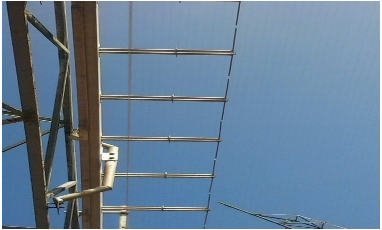
Swarup et al. Nature Physical Science(1971) vol. 230



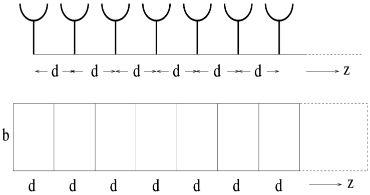


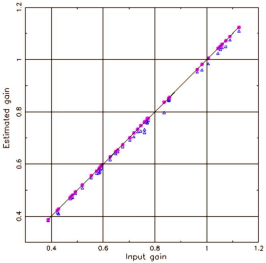
Table 1: Parameters of OWFA

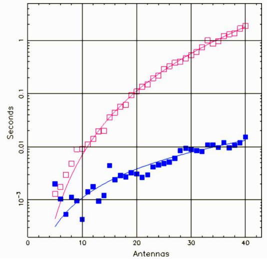
Parameter	Phase-I	Phase-II
Antennas	40	264
Total baselines	780	34716
Unique baselines	39	263
Shortest baseline	11.5 m	1.92 m
Longest baseline	448.5 m	505.0 m
Central frequency	326.5 MHz	326.5 MHz
Bandwidth	39 MHz	39 MHz
Aperture	$30 \times 11.5 cos\delta$ m^2	$30 \times 1.97 cos\delta$ m^2
FoV at $\delta = 0^\circ$	$1.8^\circ \times 4.5^\circ$	$1.8^\circ \times 27^\circ$
Resolution	0.1°	0.1°

Source: C. R. Subrahmanya , P. K. Manoharan,

Jayaram N. Chengalur, JApA (Special Issue)

Redundancy Calibration





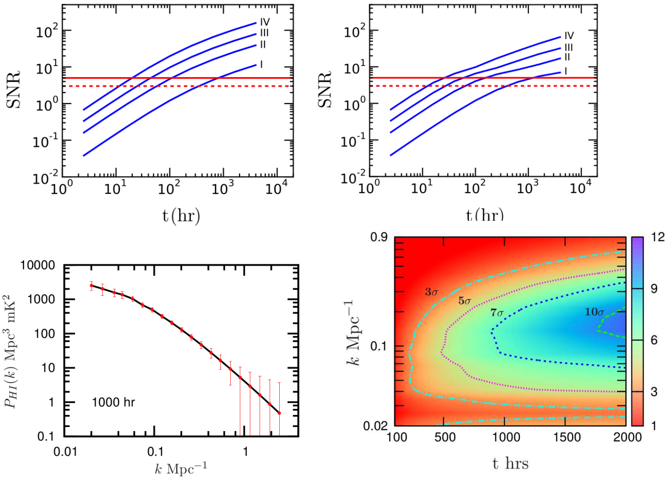
- OWFA baselines are highly redundant (Ali & Bharadwaj 2014).
- A standard iterative NLS minimization algorithm has been applied to the problem of redundancy calibration.
- NLS algorithm is fast and accurate compared to the LLS methods that have been used in the past.

Source: Marthi & Chengalur MNRAS 437, 524-531 (2014)

Science Goals

- Statistical detection of the redshifted HI 21-cm emission from the large scale structure at $z \simeq 3.35$.(Ali & Bharadwaj 2014, JApA, 35, 157)
- Monitoring of the weather in the inner solar heliosphere (via high cadence observations of a dense grid of scintillating extra-galactic radio sources).(P. K. Manoharan, C. R. Subrahmanya, and J. N. Chengalur 2016, JApA Special Issue)
- Search for transient sources like Fast Radio Bursts etc.(Bera et. al. MNRAS 457 (2016))

Fisher Matrix Prediction



Source: Bharadwaj,Sarkar, Ali(2015) JApA 36,385-398; Sarkar, Bharadwaj, Ali JApA(Special Issue)

Visibility and Visibility correlation

Visibility:

$$\mathcal{V}(\mathbf{U}_n, \nu_a) = \left(\frac{\partial B}{\partial T}\right) \int d^2\vec{\theta} A(\vec{\theta}, \nu_a) \; T(\vec{\theta}, \nu_a) e^{-2\pi i \mathbf{U}_n \cdot \vec{\theta}} \quad (1)$$

Visibility Correlation:

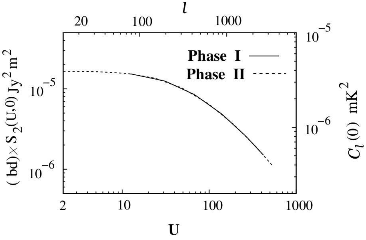
$$V_2(\mathbf{U}_n, \mathbf{U}_m, \nu, \nu + \Delta\nu) = \left(\frac{\partial B}{\partial T}\right)^2 \int d^2 U' \tilde{a}(\mathbf{U}_n - \mathbf{U}', \nu)$$
$$\times \quad \tilde{a}^*(\mathbf{U}_m - \mathbf{U}', \nu + \Delta\nu) \left[\frac{1}{\pi r^2} \int_0^\infty dk_\parallel \cos(k_\parallel r' \Delta\nu) P_T(\mathbf{k})\right] \quad (2)$$

3D spatial power spectrum of the redshifted 21-cm brightness temperature fluctuations at $z = 3.35$:

$$P_T(\mathbf{k}) = \bar{T}^2 \; \bar{x}_{\rm HI}^2 \; P_{\rm HI}(\mathbf{k}) \quad (3)$$

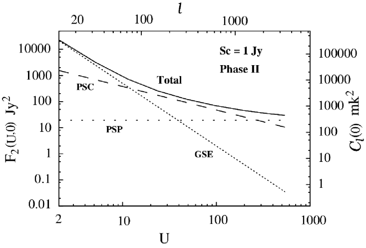
Visibility correlation of Signal & Foregrounds

HI-signal

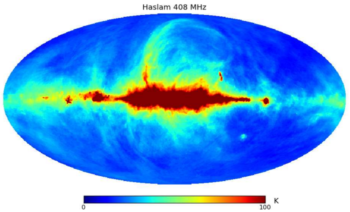


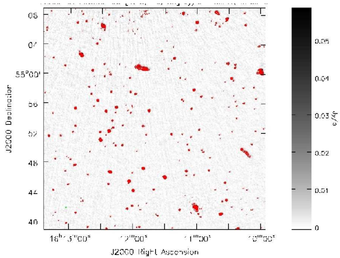
Source: Ali & Bharadwaj 2014, JApA, 35, 157

Foregrounds



Foregrounds





Source: Sirothia et. al., MNRAS 2009

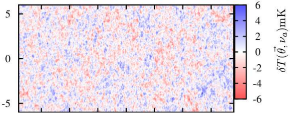
- Foregrounds are typically a few orders stronger than the cosmological HI signal(Ali & Bharadwaj 2008, Ali & Bharadwaj 2014).
- The dominant foregrounds at 327 MHz : extragalactic radio sources(point like) and the (diffuse) Galactic synchrotron emission.
- Foreground have to be subtracted properly to detect HI 21-cm signal.

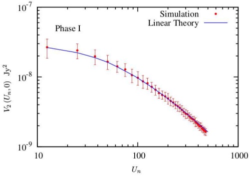
Why Simulations ?

- To introduce non-linear effects into the predictions.
- Make realistic predictions of foregrounds as seen by OWFA.
- Devise strategies for foregrounds identification and removal.
- Study the systematics introduced by the instrument, like chromaticity of the primary beam.
- An emulator "PROWESS", has been designed for OWFA (Marthi 2016 (JApA Special Issue)).

Validating the simulations

HI-Signal



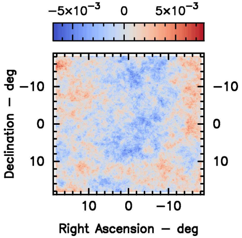


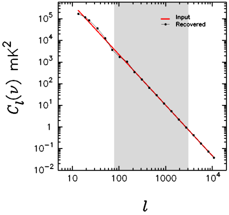
Source:Marthi, Chatterjee, chengalur & Bharadwaj (in prep),

Chatterjee, Bharadwaj, Marthi,

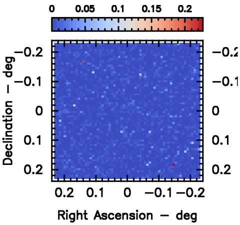
JApA (Spacial Issue)

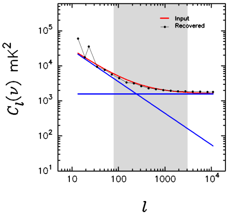
Diffuse FG



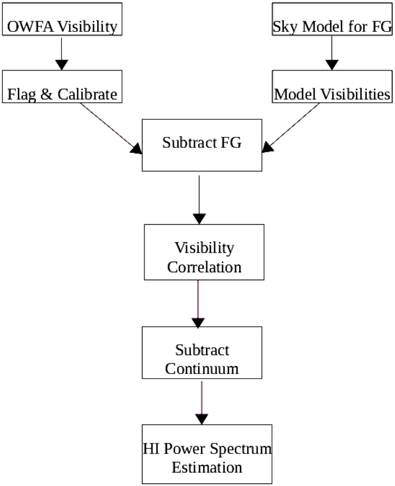


Extragalactic FG

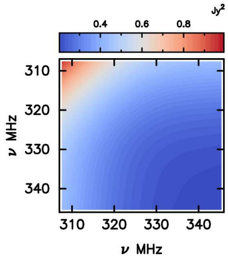


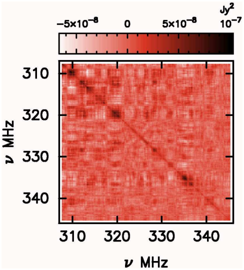


Analysis Pipeline



Visibility Correlation





- HI 21-cm signal decorrelates with in few hundreds of KHz.
- Visibility correlation of the foregrounds typically have smooth nature(Ali & Bharadwaj 2008, Ali & Bharadwaj 2014).
- Foreground removal techniques like polynomial fitting (Ghosh et al 2012), eigenvalue decomposition can be used.

Summary

- ORT is being upgraded to an interferometric facility OWFA.
- OWFA has a large instantaneous field of view, large number of redundant baselines this gives it a unique advantage for large scale and repeated surveys at metre wavelengths till SKA-low becomes operational.
- Post-EoR HI 21-cm line is an important cosmological probe. Statistical detection of HI 21-cm power spectrum will be attempted by OWFA.
- According to Fisher matrix analysis a $5-\sigma$ detection of the signal would be possible within 150 hours of observation if foregrounds are removed completely.
- Foregrounds are few order stronger than the HI 21-cm signal and poses a challenge in the detection of HI signal.
- Foreground modelling is crucial for OWFA. The chromaticity of the primary beam and the interferometer response dominates the intrinsic spectral features of the foregrounds.

Future Plans

- For OWFA Phase II which will have a much larger field of view, it is necessary to implement the spherical sky.
- For realistic foreground prediction, GMRT observations at 325 MHz can be used.
- To develop a sensitive foreground removal technique.