On the detection of Global EoR with interferometers

Saurabh Singh

Joint Astronomy Programme
Raman Research Institute

June 23, 2015
Overview

1. 21 cm signal

2. Challenges
   - Challenges in detection
   - Example

3. Alternate methods of detection
   - Dipoles
   - Aperture Antenna
   - Broadband response
   - Signal to noise ratio

4. Conclusion
1. **21 cm signal**

2. **Challenges**
   - Challenges in detection
   - Example

3. **Alternate methods of detection**
   - Dipoles
   - Aperture Antenna
   - Broadband response
   - Signal to noise ratio

4. **Conclusion**
21 cm signal : The richest probe for EoR

- Arises due to spin-flip transition in the hydrogen atom
- Since neutral hydrogen is the most abundant element in Universe from recombination to reionization, 21 cm radiation constitutes an important probe to look back in this time interval which encompasses cosmic dawn and reionization
- As various astrophysical parameters go into shaping this signal as a function of redshift, detection of 21 cm from EoR promises to address many of the unresolved question of this epoch

\[ \delta T_b = 27x_{HI}(1 + \delta) \left( \frac{\Omega_b h^2}{0.023} \right) \left( \frac{0.15}{\Omega_m h^2} \frac{1 + z}{10} \right)^{1/2} \left( \frac{T_s - T_{\gamma}}{T_s} \right) mK \] (1)

- For monopole component, it can be reduced to:

\[ \delta T_b \approx 27x_{HI} \left( \frac{T_s - T_{\gamma}}{T_s} \right) \left( \frac{1 + z}{10} \right) mK \] (2)
Study of spatial fluctuations in the 21 cm temperature requires measurement of power at different angular scales. However, we are interested in detecting monopole component of the signal which does not require high angular resolution. Single dish experiments, in principle, are sufficient to detect the global component.
Progress

1. 21 cm signal

2. Challenges
   - Challenges in detection
   - Example

3. Alternate methods of detection
   - Dipoles
   - Aperture Antenna
   - Broadband response
   - Signal to noise ratio

4. Conclusion
Challenges in the detection

Radio Frequency Interference

Foreground

Systematics

21 cm Signal
Example of modelling from SARAS 2: A single dish experiment

- The spectra obtained after calibration needs to be fit to mK accuracy
- Hence we need to model the contributions of different components and accurately subtract them
- For the present configuration, the calibrated spectra is modelled as follows:

\[
T_{\text{observed}} = T_{\text{sky}}(1 - |\Gamma|^2) - T_{\text{ref0}} + T_{\text{receiver}} + T_{\text{ohmic}}
\]  

(3)

where \( T_{\text{receiver}} = |\Gamma| (f_1 V_{n1}^2 + f_2 V_{n2}^2) \cos(\phi + \phi_a) \)
Progress

1 21 cm signal

2 Challenges
   - Challenges in detection
   - Example

3 Alternate methods of detection
   - Dipoles
   - Aperture Antenna
   - Broadband response
   - Signal to noise ratio

4 Conclusion
Can we use Interferometers?¹

- Modelling receiver noise to mK level is a daunting task
- Interferometers are insensitive to receiver noise which is uncorrelated

\[ V(\vec{b}, \nu) = \frac{1}{4\pi} T_{sky}(\nu) \int A(\vec{r}, \nu) e^{-i2\pi \frac{\vec{b} \cdot \vec{r}}{\lambda}} d\Omega \]  

Configurations: 1) Short dipoles

Dipole radiation pattern
Inline and Parallel configuration

Inline Configuration

Parallel Configuration

![Graph showing visibility amplitude vs baseline in wavelengths for different configurations of antennas: isotropic antennas, dipole antennas in parallel configuration, and dipole antennas in in-line configuration.](image)
Inline and Parallel configuration for 1D arrays

Inline array in inline Configuration

Inline array in parallel Configuration

Graph 1: Visibility Amplitude vs. Baseline in wavelengths
- 8 dipole antennas
- 4 dipole antennas
- 2 dipole antennas

Graph 2: Visibility Amplitude vs. Baseline in wavelengths
- Isotropic antennas
- 8 dipole antennas
- 4 dipole antennas
- 2 dipole antennas
Configurations: 2) Aperture Antenna

- Can be considered to be summation over elemental antenna
- The visibility averages out over the area and hence contribution is highly reduced
- Response further deteriorates once Gaussian taper is used \((10^{-7})\)
Based on above configurations, **inline array in parallel configuration** has maximum response.

We search for set of baselines such that we have non zero net response at any frequency.

We take three antenna arrays spaced at $\lambda_{max}$ and 1.5$\lambda_{max}$.

Ensures that visibilities are sampled at $b/\lambda > 1$ at all frequencies.
Broadband response: More Configurations

- We further add **1D apertures** and **Zero baseline interferometer** as candidates for comparison for broadband response.
- 1D apertures are fully filled at all frequencies and would have higher sensitivity at higher frequencies.
- Zero baseline interferometer uses pair of dipoles with a space beam splitter placed vertically between them.
We assume that system temperature is dominated by antenna temperature given as:

\[ T_a = 200 \left( \frac{f}{150 \text{ MHz}} \right)^{-2.5} \text{ K} \]  \hspace{1cm} (5)

Taking weighted averaging of the responses from different baselines, we obtain signal to noise ratio as a function of frequency for three configurations.
Progress

1. 21 cm signal

2. Challenges
   - Challenges in detection
   - Example

3. Alternate methods of detection
   - Dipoles
   - Aperture Antenna
   - Broadband response
   - Signal to noise ratio

4. Conclusion
Conclusions

- Detection of 21 cm signal from EoR promises to answer many unsolved questions about the epoch
- The detection is challenging due to large dynamic range requirement as well precise system calibration
- Interferometers, in particular configurations, can indeed be used for detection of global signals
- Due to extremely reduced response from aperture antennas, efforts for interferometer detection of monopole component should be done using elemental antennas
- We have shown that particular configurations, namely 1D arrays and 1D apertures in parallel configuration as well as zero baseline interferometers, can be effectively used for detection of broadband global signal
References

- Pritchard, J. R., & Loeb, A. 2012, Reports on Progress in Physics, 75, 086901

Image Credits

- Pritchard, J. R., & Loeb, A. 2012, Reports on Progress in Physics, 75, 086901
Thanks!