Title and abstract

1) Statistics of the epoch of reionization (EoR) 21-cm signal: The power spectrum error-covariance

Speaker: Rajesh Mondal (IIT KGP)

Abstract: The EoR 21-cm signal is expected to become highly non-Gaussian as reionization progresses. This severely affects the error-covariance of the EoR 21-cm power spectrum which is important for predicting the prospects of a detection with ongoing and future experiments. Most earlier works have assumed that the EoR 21-cm signal is a Gaussian random field where (1) the error variance depends only on the power spectrum and the number of Fourier modes in the particular k bin, and (2) the errors in the different k bins are uncorrelated. Here we use an ensemble of simulated 21-cm maps to analysis the error-covariance at various stages of reionization. We find that even at the very early stages of reionization (x_HI~0.9) the error variance significantly exceeds the Gaussian predictions at small length-scales ($k > 0.5$ Mpc^{-1}) while they are consistent at larger scales. The errors in most k bins (both large and small scales), are however found to be correlated. Considering the later stages (x_HI = 0.15), the error variance shows an excess in all k bins within $k \geq 0.1$ Mpc^{-1}, and it is around 200 times larger than the Gaussian prediction at $k \sim 1$ Mpc^{-1}. The errors in the different k bins are all also highly correlated, barring the two smallest k bins which are anti-correlated with the other bins. Our results imply that the predictions for different 21-cm experiments based on the Gaussian assumption underestimate the errors, and it is necessary to incorporate the non-Gaussianity for more realistic predictions.

2. Point Source Modelling and Removal

Speaker: Nirupam Roy (IISc, Bangalore)

Abstract: Characterizing and removing/avoiding point source foreground for studying the diffuse and weak signal is both computationally challenging and expensive. I will discuss some work on this from our group, and similar efforts from others in recent times. Numerical simulations seem to indicate that some recent development of imaging algorithms are going to be very useful in modelling and subtracting point sources for low frequency observations targeting diffuse cosmological signal.

3. FOREGROUND SIMULATION FOR GMRT 150 MHz OBSERVATION

Speaker: Srijita Pal (IIT KGP)

Abstract: Before making any effort to detect the very important 21-cm HI signal using currently existing instruments, first it is important to understand the contributions of the foregrounds because of their overwhelming presence in any radio observation. In the work to be presented, first the foreground has been generated at 150 MHz using currently existing models and mainly consists of two components. Using the observed differential source counts, the sky has been populated with the Poisson distribution of the point sources. For the second component: the diffuse galactic synchrotron radiation, brightness temperature fluctuations have been generated using a known

angular power spectrum. Next, the visibility data due to these foregrounds, as observed by a radiotelescope , have been simulated for the GMRT configuration.

4. HI 21-cm imaging of first sources with SKA

Speaker: Raghunath Ghara (NCRA-TIFR, Pune)

Abstract : Understanding the properties of the very first sources in the Universe using the redshifted 21-cm signal from the cosmic dawn and epoch of reionization is one of the aims of present day low-frequency experiments. Here we investigate the detectability of early sources like primordial galaxies, mini-QSOs and high-mass X-ray binaries using imaging techniques for the SKA1-low. We find that after subtracting the foregrounds sufficiently and suppressing the noise by smoothing the maps using a Gaussian filter, the sources are detectable with $\sim 9 -\sigma$ confident level over 2000 h of observation with the SKA1-low. Though the recovered brightness temperature profiles around the sources are modified due to the Gaussian smoothing, still these can be used to extract the source parameters. The signal to noise ratio increases with the size of the Gaussian filter. Thus, one possible strategy for the future radio experiments with the SKA1-low could be to observe multiple fields and first, detect the signal within short observation time like 200 h by smoothing the images over large scales. Once the signal is detected in some field, one can go for longer observation to that field to enhance the signal to noise ratio, which will be useful for parameter estimation of the sources.

5. Foreground Challenges for 21cm Cosmology Observations - Current Status

Speaker: Abhirup Datta (IIT Indore)

6. Global 21cm Observations - current status and future directions

Speaker: Abhirup Datta (IIT Indore)

7. Biography of Neutral Hydrogen -From recombination to reionization

Speaker: Prasun Dutta (IIT BHU, Varanasi)

Abstract: At a redshift of about 1100 the universe had cooled down enough to form neutral hydrogen atoms for the first time. This rarified the free electrons left to do Thompson scattering with the photons, the radiation became decoupled. This radiation provides a cosmic background (CMBR) of all the radiation we receive from space. The neutral hydrogen started to cluster gravitationally, eventually formed the first stars. Radiation from these first luminous objects re ionized the universe at about a redshift of 10. Afterwards, only pockets of neutral hydrogen were left mostly in the galaxies.

Observation of the angular and frequency variation of redshifted 21 cm radiation intensity from the neutral hydrogen holds the key to understand the evolution of the structures, particularly the matter power spectrum of the universe, in principle right from the recombination to the reionization . The 21 cm radiation intensity is governed by the baryonic density, neutral fraction, collisional processes

and interaction of the hydrogen atom with CMB and Lyman alpha radiation etc. The basic physics behind these processes would be reviewed.

8. Imprints of recombination history of the Universe on HI 21-cm signal during dark ages

Speaker: Dhruba Dutta Chowdhury (Presidency University, Kolkata)

Abstract: In the evolutionary history of the Universe, the epoch of recombination is followed by the Dark Ages. This a time during which the Universe was predominantly neutral until the first sources of light appeared and reionization began. The redshifted 21 cm signal from neutral hydrogen can be used to observationally probe this era for those redshifts at which the neutral hydrogen spin temperature is significantly different from the CMB temperature. In this talk, I will critically examine different models that can be found in the literature for analytically calculating the evolution of the kinetic gas temperature, spin temperature and their first order perturbations during the Dark Ages. I will show that careful consideration of recombination physics such as detailed modelling for the electron ionization fraction during the Dark Ages is required for accurately predicting the brightness temperature and neutral hydrogen power spectrum.

9. Challenges in modelling the cosmic reionization

Speaker: Tirthankar Roy Choudhury (NCRA-TIFR, Pune)

Abstract: The study of the epoch of reionization has acquired significance in recent times because of the large number of telescopes attempting to observe it. These observations must be complemented by detailed theoretical models in order to interpret the results. We plan to review some of the major challenges that one encounters while building these models.

10. Present constraints on cosmic reionization

Speaker: Tirthankar Roy Choudhury (NCRA-TIFR, Pune)

Abstract: In recent times there have been a number of experiments that have targetted the high redshift universe. These observations can be related to understanding the reionization epoch. In this talk, we will review the current constraints obtained on the reionization using a variety of data sets. We will also discuss the implications of these results in terms of understanding the properties of the sources responsible for reionization.

11. Measurements of Foreground with GMRT for redshifted 21-cm studies

Speaker: Sk. Saiyad Ali (Jadavpur University, Kolkata)

Abstract: Observations of the redshifted 21cm radiation have become the most promising future probes of the Universe from dark ages to present epoch. The removal of continuum foregrounds sources is one of the major challenges for detecting the faint cosmological HI signal. The foregrounds are expected to be roughly 4-5 orders of magnitude stronger than the cosmological HI signal. We use 150 MHz GMRT observations to characterise the statistical properties of the

background radiation across one degree to sub-arcminute angular scale and across the frequency band of 2.5 MHz with 62.5 kHz resolution. The measured multifrequency angular power spectrum is found to have values in the range 10^4 - 2*10^4 mK^2 across $700 \leq l \leq 2 \times 10^4$ and frequency $\leq$ 2.5 MHz, which is consistent with model predictions where point sources are the most dominant foreground component. The measured angular power spectrum does not show a smooth frequency dependence, which poses a severe difficulty for foreground removal using polynomial fitting. We have used the most sensitive observing FIELD, which has an rms noise of 1.3 mJy/beam , to study the properties of the radio source population to a limiting flux of 9 mJy. The differential source count is well fitted with a single power law of slope −1.6. Further, the diffuse Galactic emission is revealed after the point sources ($S \geq 10$ mJy) are subtracted out from the same FIELD. We find angular power spectrum $\propto -2.34$ for $253 \leq l \leq 800$ which is characteristic of the Galactic synchrotron radiation measured at higher frequencies and larger angular scales

Further, we use GMRT 610 MHz data to measure total the multi -frequency angular power spectrum of the entire sky signal. Using the same data we show that we successful remove the foreground at l= 1405, 1602 and 1876 with 4th order polynomial fitting where we use tapering technique to suppress the contribution from the outer regions of the telescope's field of view.

12. Visibility Correlations: What have we learnt so far?

Speaker: Somnath Bharadwaj (IIT KGP)

Abstract: Visibility correlations present a technique to quantify the statistical properties of the cosmological 21-cm signal as measured in radio interferomeric observations. The talk will summarize the work carried out by the speaker and his collaborators, and highlight what we have leaned from these studies.

13. Matched filter search for ionised bubbles during reionization epoch

Speaker: Kanan K. Datta (Presidency University, Kolkata)

Abstract: Detection of individual luminous sources during the reionization epoch and cosmic dawn through their signatures in the HI 21- cm signal is one of the direct approaches to probe the epoch. We will summarize our past and ongoing works on this and present preliminary results on the prospects of detecting such sources using the SKA1-low experiment.

14. The visibility based Tapered Gridded Estimator (TGE) for the redshifted 21-cm power spectrum

Speaker: Samir Choudhuri (IIT KGP)

Abstract: We present the visibility based Tapered Gridded Estimator (TGE) for the power spectrum of the diffuse sky signal. The visibilities are gridded to reduce the computation, and tapered through a convolution to suppress the contribution from the outer regions of the telescope's field of view.

The TGE also internally estimates the noise bias, and exactly subtracts this out to give an unbiased estimate of the power spectrum. An earlier version of the 2D TGE for the angular power spectrum C l is improved and then extended to obtain the 3D TGE for the power spectrum P (k) of the 21-cm brightness temperature fluctuations. Analytic formulas are also presented for predicting the variance of the binned power spectrum. The estimator and its variance predictions are validated using simulations of 150 MHz GMRT observations. We find that the estimator accurately recovers the input model for the 1D Spherical Power Spectrum P (k) and the 2D Cylindrical Power Spectrum P (k ⊥ , k), and the predicted variance is also in reasonably good agreement with the simulations.

15. Semi-Numerical Simulations for EoR 21-cm Signal

Speaker: Abinash K. Shaw (IIT KGP)

Abstract: Observations of the redshifted HI 21-cm signal provide a window into the Epoch of Reionization (EoR). Reionization involves various physical processes, many of which are still unknown. There are several ongoing and upcoming 21-cm surveys which promise to detect the EoR 21-cm signal through radio interferometry. Numerical simulations of the EoR 21-cm signal are important to model the nature of the signal, restrict the parameter space for the detection and extraction of required data. There are several methods to simulate the signal. Full radiative transfer techniques are most accurate and incorporate all the process and sources, but are computationally extremely challenging. As an alternative to radiative transfer simulations, we do some approximations on physical processes but can simulate the signal in a large volume with limited computing resources. This is a review of the semi-numerical simulations of EoR 21-cm signal. The pipeline involves three major steps: (1) N-body simulations to generate dark matter density field distributions using parallelized Particle Mesh (PM) code. (2) Identification of halos using Friends-of-Friend (FoF) algorithm. (3) Excursion set formalism to generate reionization map under the assumption that the collapsed haloes host the ionising sources and the neutral hydrogen (HI) exactly traces the dark matter. We also assume that the number of ionizing photons from a collapsed halo is proportional to its mass.