Abstract

The cosmic dawn (CD) and epoch of reionization (EoR) is one of the least understood episodes of universe. The cosmological 21-cm signal from neutral hydrogen, which is considered as a promising tool, is being used to observe and study the epoch. A significant part of this thesis focuses on the semi-analytical modeling of the global HI 21-cm signal from CD considering several physical processes. Further, it investigates the nature of galaxies that dominate during CD and EoR using current available observations.

Understanding different physical processes through which the thermal and ionization states of the intergalactic medium (IGM) during CD and EoR evolved is the key to unlocking the mysteries of the early universe. The study of the 21-cm signal is a powerful tool that can be used to investigate different physical processes in the early universe. It provides us with a window into the time before the formation of the first galaxies. Our study is partly motivated by the first-ever detection of the global 21-cm signal reported by the EDGES low-band antenna and ongoing observations by several global 21-cm experiments. One of the promising avenues to interpret the EDGES signal is to consider a 'colder IGM' background.

In our first work, we study the redshift evolution of the primordial magnetic field (PMF) during the dark ages and cosmic dawn and prospects of constraining it in light of EDGES 21-cm signal in the 'colder IGM' background. Our analysis has been carried out by considering the dark matter-baryon interactions for the excess cooling mechanism. We find that the colder IGM suppresses both the residual free electron fraction and the coupling coefficient between the ionized and neutral components. The Compton heating also gets affected in colder IGM backgrounds. Consequently, the IGM heating rate due to the PMF enhances compared to the standard scenario. Thus, a significant fraction of the magnetic energy, for $B_0 \lesssim 0.5\,\mathrm{nG}$, get transferred to the IGM, and the magnetic field decays at a much faster rate compared to the simple $(1+z)^2$ scaling during the dark ages and cosmic dawn. We also find that the upper limit on the PMF depends on the underlying DM-baryon interaction. Higher PMF can be allowed when the interaction

cross-section is higher and/or the DM particle mass is lower. Our study shows that the PMF with B_0 up to $\sim 0.4\,\mathrm{nG}$, which is ruled out in the standard model, can be allowed if DM-baryon interaction with suitable cross-section and DM mass is considered. However, this low PMF is an unlikely candidate for explaining the rise of the EDGES absorption signal at lower redshift.

We further consider, in detail, the heating of the IGM owing to cosmic ray protons generated by the supernovae from both early Pop III and Pop II stars. The low-energy cosmic ray protons from Pop III supernovae can escape from minihalos and heat the IGM via collision and ionization of hydrogen. Moreover, the high-energy protons generated in Pop II supernovae can escape the hosting halos and heat the IGM via magnetosonic Alfvén waves. We show that the heating due to these cosmic ray particles can significantly impact the IGM temperature and hence the global 21-cm signal at $z \sim 14-18$. The depth, location, and duration of the 21-cm absorption profile are highly dependent on the efficiencies of cosmic ray heating and star formation rate. In particular, the EDGES signal can be well fitted by the cosmic ray heating along with the Lyman-α coupling and the dark matter-baryon interaction that we consider to achieve a 'colder IGM background'. Further, we argue that the properties of cosmic rays and the nature of the first generation of stars could be constrained by accurately measuring the global 21-cm absorption signal during the cosmic dawn.

We, further, explore the conditions by which the EDGES detection is consistent with current reionization and post-reionization observations, including the volume-averaged neutral hydrogen fraction of the intergalactic medium at $z \sim 6$–8, the optical depth to the cosmic microwave background, and the integrated ionizing emissivity at $z \sim 5$. By coupling a physically motivated source model derived from radiative transfer hydrodynamic simulations of reionization to a Markov Chain Monte Carlo sampler, we find that high contribution from low-mass halos along with high photon escape fractions are required to simultaneously reproduce the high-redshift (cosmic dawn) and low-redshift (reionization) existing constraints. Low-mass faint-galaxies dominated models produce a flatter emissivity evolution that results in an earlier onset of reionization with gradual and longer duration and higher optical depth. Our results provide insights into the role of faint and bright galaxies during cosmic reionization, which can be tested by upcoming surveys with the James Webb Space Telescope (JWST).

With the extreme effort in building more advanced and sophisticated telescopes, such as the Square Kilometre Array (SKA) and several global 21-cm telescopes the future 21-cm signal detection would be able to provide better constraints on the amplitude of PMF and the efficiencies on cosmic ray protons, and consequently on early star formation rates. We would be able to get a more complete picture of the cosmic dawn and the epoch of reionization by combining the future detection of the 21-cm signal with other observational constraints at high redshifts.