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Estimation of Reionization Parameters from 21-cm Bispectrum using BNN-based Emulator

The upcoming large scale surveys like SKA, LOFAR and HERA will soon start probing the Universe in the era of Cosmic Dawn (CD) and Epoch of Reionization (EoR). To understand and interpret the observations from various experiments we need novel data analysis and interpretation techniques, which involve fast simulations of the expected signal, developing statistics for interpreting the signal and optimal parameter estimation techniques. The 21-cm signal coming from the CD-EoR is expected to be highly non-Gaussian and the signal power spectrum will not be able to quantify this non-Gaussianity. Therefore, we need a higher-order signal statistic, e.g. bispectrum, to probe this time-evolving non-Gaussianity. We have developed the parameter estimation pipeline that allows us to constrain the EoR parameters from the 21-cm bispectrum using Bayesian Inference techniques. The statistical inference from these observations will require rerunning the computationally expensive numerical simulations of CD-EoR for a large number of times (> 106 - 108 times). To bypass this potential bottleneck, we have developed a neural network based emulator to predict the EoR 21-cm bispectrum for given reionization parameters. The previous works [1,2] on parameter estimation of the EoR using Artificial Neural Network (ANN) based emulators for 21-cm signal summary statistics had a fundamental drawback. These ANN based emulators can produce only point value predictions of the target signal statistic, thus they fail to capture the uncertainty in their predictions. Thus when such emulators are used in the Bayesian inference pipeline, they can not naturally propagate their prediction uncertainties to the estimated model parameters. To solve this problem, we have, for the first time, developed the bispectrum emulator using the Bayesian Neural Network (BNN). The BNNs use the MCMC framework to get the posterior distribution of its learning parameters (i.e, weights and biases) that results in the posterior distribution of the output signal. So, the BNN based emulators are capable of quantifying the uncertainty in the predicted output. Using this emulator we demonstrate that our EoR parameter estimation turned out to be more robust.

[1] H. Tiwari, A. Shaw, S. Majumdar, M. Kamran, M. Choudhury et al., JCAP, 04, 045, 27 (2022)
[2] N. S. Kern, A. Liu, A. R. Parsons, A. Mesinger, and B. Greig , Astrophys. J. 1 23, 848 (2017).

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