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Constraining the First Billion Years: Investigative Study on SKA-Low Primary Beam Uncertainties and Inference

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In an attempt to track our Universe's past, one of the most prominent gaps in our understanding is the period of the "Cosmic Dawn." The period extends for about 50 million years to one billion years after the Big Bang when the first stars, black holes, and galaxies in the Universe formed. One of the best ways to observe this era is with low-frequency radio telescopes, which can observe the redshifted "spin-flip" radiation from the hydrogen that pervades the Universe during the Cosmic Dawn.

The inception of the upcoming SKA-telescope with unprecedented sensitivity is our best bet for detecting the 21-cm signal. However, one of the well-known hurdles faced by the community in detecting the HI signal is that of foreground mitigation and instrumental uncertainties. Previous studies [1, 2] have shown that our measurements are also forecasted to be plagued by errors due to uncertainties in the primary beam. These errors are manifested as artifacts in the 2-d cylindrical power spectrum and may hinder our insights into the EOR window. This warrants a thorough study of techniques that can recognize, and mitigate these effects.

For frequencies residing within the speculated EoR region, we use OSKAR package to perform simulations of 'perturbed' beams incorporating these errors along with an updated vogel layout of the SKA telescope. We use existing numerical techniques like Principal Component Analysis PCA [1] and novel deep-learning methods to reconstruct a residual beam model. We develop a pipeline that quantifies their contamination by convolving the perturbed beams with simulated HI signal plus foregrounds and evaluating the cylindrical power spectrum.

1. Nasirudin, A., Prelogovic, D., Murray, S. G., Mesinger, A., and Bernardi, G., "Characterizing beam errors for radio interferometric observations of reionization", Monthly Notices of the Royal Astronomical Society, vol. 514, no. 3, OUP, pp. 4655–4668, 2022. doi:10.1093/mnras/stac1588.

2. Mazumder, A., "Synthetic observations with the Square Kilometre Array: Development towards an end-to-end pipeline",Journal of Astrophysics and Astronomy , vol. 44, no. 1, Springer, 2023. doi:10.1007/s12036-022-09906-8.