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Simulation-based inference for parameter estimation of high-redshift sources with the Einstein telescope

The Einstein Telescope (ET) will be a key instrument for detecting gravitational waves (GWs) in the coming decades. However, analyzing the data and estimating source parameters will be challenging, especially given the large number of expected detections—between 10^4 and 10^5 per year—which makes current methods based on stochastic sampling impractical. In this work, we use DingoIS to perform Neural Posterior Estimation (NPE), a simulation-based inference technique that leverages normalizing flows to approximate the posterior distribution of detected events. After training, inference is fast, requiring only a few minutes per source, and accurate, as validated through importance sampling. We process 1000 randomly selected injections and achieve an average sample efficiency of $\sim 13\%$, which increases to $\sim 18\%$ ($\sim 20\%$) if we consider only sources merging at redshift $z > 4$ ($z > 10$). To confirm previous findings on ET ability to estimate parameters for high-redshift sources, we compare NPE results with predictions from the Fisher information matrix (FIM) approximation. We find that FIM underestimates sky localization errors by a factor of > 8, as it does not capture the multimodalities in sky localization introduced by the geometry of the triangular detector. On the contrary, FIM overestimates the uncertainty in luminosity distance by a factor of ~ 3 on average when the injected luminosity distance $d_{\mathrm{L}}^{\mathrm{inj}} > 10^5$ Mpc, further confirming that ET will be particularly well suited for studying the early Universe.

AI keywords

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