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Fast and accurate parameter estimation of high-redshift sources with the Einstein Telescope

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The Einstein Telescope (ET) and other third-generation (3G) gravitational wave (GW) detectors will be key instruments 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) of high-redshift events detectable with ET. NPE is a likelihood-free inference technique that leverages normalizing flows to approximate posterior distributions. After training, inference is fast, requiring only a few minutes per source, and accurate, as corrected through importance sampling and validated against standard inference methods like Bilby. We process 1000 high-redshift short-lived binary black holes (BBHs) and achieve an average sample efficiency of $\sim 13\%$, which increases to $\sim 20\%$ if we consider only sources merging at redshift $z > 10$. 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.

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