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Gravitational-wave parameter estimation with relative binning: Inclusion of higher-order modes and precession, and applications to lensing and third-generation detectors

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Once a gravitational wave signal is detected, the measurement of its source parameters is important to achieve various scientific goals. This is done through Bayesian inference, where the analysis cost increases with the model complexity and the signal duration. For typical binary black hole signals with precession and higher-order modes, one has 15 model parameters. With standard methods, such analyses require at least a few days. For strong gravitational wave lensing, where multiple images of the same signal are produced, the joint analysis of two data streams requires 19 parameters, further increasing the complexity and run time. Moreover, for third generation detectors, due to the lowered minimum sensitive frequency, the signal duration increases, leading to even longer analysis times. With the increased detection rate, such analyses can then become intractable. In this work, we present a fast and precise parameter estimation method relying on relative binning and capable of including higher-order modes and precession. We also extend the method to perform joint Bayesian inference for lensed gravitational wave signals. Then, we compare its accuracy and speed to those of state-of-the-art parameter estimation routines by analyzing a set of simulated signals for the current and third generation of interferometers. Additionally, for the first time, we analyze some real events known to contain higher-order modes with relative binning. For binary black hole systems with a total mass larger than $50M_{\odot}$, our method is about 2.5 times faster than current techniques. This speed-up increases for lower masses, with the analysis time being reduced by a factor of 10 on average. In all cases, the recovered posterior probability distributions for the parameters match those found with traditional techniques.

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