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Modeling Non-Gaussianities using Gaussian Mixture Models

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In Pulsar Timing Array (PTA) data analysis, noise is typically assumed to be Gaussian, and the marginalized likelihood has a well-established analytical form derived within the framework of Gaussian processes. However, this Gaussianity assumption may break down for certain classes of astrophysical and cosmological signals, particularly for a gravitational wave background (GWB) generated by a population of supermassive black hole binaries (SMBHBs). In this work, we present a new method for testing the presence of non-Gaussian features in PTA data. We go beyond the Gaussian assumption by modeling the noise or signal statistics using a Gaussian mixture model (GMM). An advantage of this approach is that the marginalization of the likelihood remains fully analytical, expressed as a linear combination of Gaussian PTA likelihoods. This makes the method straightforward to implement within existing data analysis tools. Moreover, this method extends beyond the free spectrum analysis by producing posterior probability distributions of higher-order moments inferred from the data, which can be incorporated into spectral refitting techniques. We validate the model using simulations and demonstrate the sensitivity of PTAs to non-Gaussianity by computing the Bayes factor in favor of the GMM as a function of the injected excess moments. We apply the method to a more astrophysically motivated scenario where a single SMBHB is resolved on top of a realistic GWB and show that significant non-Gaussianities are introduced by the individual source. Finally, we search for non-Gaussianities in the EPTA DR2 dataset.

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