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Angular power spectra of anisotropic stochastic gravitational wave background: Developing statistical methods and analyzing data from ground-based detectors

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Unresolved sources of gravitational waves can create a stochastic gravitational wave background (SGWB) which may have intrinsic or extrinsic anisotropies. The angular power spectrum is a well-suited estimator for characterizing diffuse anisotropic distributions in the sky. Here we estimate the first model-independent all-sky all-frequency SGWB angular power spectra in the 20-1726 Hz frequency range from the third observing run (O3) of the Advanced LIGO and Advanced Virgo detectors. We develop a method to use the spectrum's signal-to-noise ratio as the detection statistic and show that the shape of the distribution of the statistic obtained from the data agrees with the analytical model with a modified value of the parameter. Since we find the data to be consistent with noise, 95% confidence Bayesian upper limits are set on the angular power spectra, ranging from $C_\ell^{1/2} \leq (3.0 \times 10^{-9} - 0.73)$ sr^{-1}. We also introduce a method to combine the narrow band angular power spectra to obtain estimators for broadband SGWB. These results can directly constrain theoretical models that predict the SGWB angular power spectra and for estimating or constraining the corresponding parameters. In addition, the results and the techniques introduced in this work can be useful for performing correlation-based searches, for instance, with electromagnetic observations.

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