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Cosmic variance in the nanohertz gravitational wave background

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We use large N-body simulations and empirical scaling relations between dark matter halos, galaxies, and supermassive black holes to estimate the formation rates of supermassive black hole binaries and the resulting low-frequency stochastic gravitational wave background (GWB). We find that uncertainty in the astrophysical scaling relations systematically changes the amplitude of the GWB by a factor of ~2, and that this range is already constrained by recent pulsar timing array upper limits. We investigate the Poisson variance in the amplitude of the GWB for randomly-generated populations of supermassive black holes, finding a scatter of order unity per frequency bin below 10 nHz, and increasing to a factor of ~10 near 100 nHz. This variance is a result of the rarity of the most massive binaries, which dominate the signal, and acts as a fundamental uncertainty on the amplitude of the underlying power law spectrum. This Poisson uncertainty dominates above 20 nHz, while at lower frequencies it is subdominant to that due to our poor understanding of the astrophysical scaling relations. At very low frequencies, uncertainties related to the final parsec problem and the processes which drive binaries to the gravitational wave dominated regime may affect both the astrophysical and Poisson variance in the spectrum of the GWB.

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