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Revisiting gravitational wave background from primordial black holes

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The Peters formula, which tells how the coalescence time of a binary system emitting gravitational radiation is determined by the initial size and shape of the elliptic orbit, is often used in estimating the merger rate of primordial black holes and the gravitational wave background from the mergers. Valid as it is in some interesting scenarios, such as the analysis of the LIGO-Virgo events, the Peters formula fails to describe the coalescence time if the orbital period of the binary exceeds the value given by the formula. This could underestimate the merger rate of some binaries. As a result, the energy density spectrum of the gravitational wave background could develop a peak, which is from mergers occurring at either $t \sim 10^{13}$ s (for black holes with mass $M > 10^8 M_\odot$) or t $10^{26}(M/M_\odot)^{-5/3}$ s (for $10^5 M_\odot < M < 10^8 M_\odot$). This can be used to constrain the fraction of dark matter in primordial black holes (denoted by f) if potential probes (such as SKA and U-DECIGO) do not discover such a background, with the result $f < 10^{-6} - 10^{-4}$ for the mass range $10 - 10^9 M_\odot$. We then consider the effect of mass accretion onto primordial black holes at redshift z 10, and find that the merger rate could drop significantly at low redshifts. The spectrum of the gravitational wave background thus gets suppressed at the high-frequency end. This feature might be captured by future detectors such as ET and CE for initial black hole mass $M = \mathcal{O}(10 - 100) M_\odot$ with $f > 10^{-4}$.
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