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Superradiant dark matter production from primordial black holes

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Rotating primordial black holes (PBHs) in the early universe can emit particles through superradiance, a process particularly efficient when the particle's Compton wavelength is comparable to the PBH's gravitational radius. Superradiance leads to an exponential growth of particle occupation numbers in gravitationally bound states. We present an analysis of heavy bosonic dark matter (DM) production through three gravitational mechanisms: Hawking radiation, superradiant instabilities, and ultraviolet (UV) freeze-in. We consider PBHs that evaporate before Big Bang Nucleosynthesis (BBN). For both scalar and vector DM, our analysis incorporates the evolution of a second superradiant mode. We demonstrate that the growth of a second superradiant mode causes the decay of the first mode, and thus the second mode cannot further enhance the DM abundance beyond that already achieved by the first mode. Our study also reveals that while superradiance generally enhances DM production, gravitational wave (GW) emission from the superradiant cloud may significantly modify this picture. For scalar DM, GW emission reduces the parameter space where superradiance effectively augments relic abundance. For vector DM, rapid GW emission from the superradiant cloud may yield relic abundances below those achieved through Hawking radiation alone. These findings demonstrate that multiple-mode effect and GW emission play critical roles in modeling DM production from PBHs in the early universe.

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