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Black hole superradiance of self-interacting scalar fields

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Black hole superradiance is a powerful probe of light, weakly-coupled hidden sector particles. Many candidate particles, such as axions, generically have self-interactions that can influence the evolution of the superradiant instability. As pointed out in arXiv:1604.06422 in the context of a toy model, much of the existing literature on spin-0 superradiance does not take into account the most important self-interaction-induced processes. These processes lead to energy exchange between quasi-bound levels and particle emission to infinity; for large self-couplings, superradiant growth is saturated at a quasi-equilibrium configuration of reduced level occupation numbers. In this paper, we perform a detailed analysis of the rich dynamics of spin-0 superradiance with self-interactions, and the resulting observational signatures. We focus on quartic self-interactions, which dominate the evolution for most models of interest. We explore multiple distinct regimes of parameter space introduced by a non-zero self-interaction, including the simultaneous population of two or more bound levels; at large coupling, we confirm the basic picture of quasi-equilibrium saturation and provide evidence that the "bosenova" collapse does not occur in most of the astrophysical parameter space. Compared to gravitational superradiance, we find that gravitational wave "annihilation" signals and black hole spin-down are parametrically suppressed with increasing interactions, while new gravitational wave "transition" signals can take place for moderate interactions. The novel phenomenon of scalar wave emission is less suppressed at large couplings, and if the particle has Standard Model interactions, then coherent, monochromatic axion wave signals from black hole superradiance may be detectable in proposed axion dark matter experiments.

Primary author: SIMON, Olivier

Co-authors: GALANIS, Marios (Stanford University); BARYAKHTAR, Olivier (University of Washington); LASENBY, Robert (Stanford University)

Presenter: SIMON, Olivier

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