Abstract for IAS Focused Program on Mathematical Foundations of Topological Materials (January 6-9, 2026)

Band Structure and Dynamics of Single Photons in Atomic Lattices

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We present a framework to investigate the collective properties of atomic lattices in one, two, and three dimensions. We analyze the single-photon band structure and associated atomic decay rates, revealing a fundamental dependence on dimensionality. One- and two-dimensional arrays are shown to be inherently radiative, exhibiting polaritonic band gaps and decay rates that oscillate between superradiant and subradiant regimes, as a function of lattice spacing. In contrast, three-dimensional lattices are found to be fundamentally non-radiative due to the inhibition of spontaneous emission, with decay channels opening only at discrete Bragg resonances. Furthermore, we demonstrate that this structural difference dictates the system dynamics, which transitions from dissipative decay in lower dimensions to coherent transport in three dimensions. Our results provide insight into the cooperative effects of atomic arrays at the single-photon level.