INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
PhD-17 SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

In this thesis we present an analytical and numerical investigation of collective excitations and emergent quantum phases in spin-orbit coupled spin-1 Bose-Einstein condensates with ferromagnetic and antiferromagnetic interactions. We first analyze the ground-state phases and quench dynamics of quasi-one-dimensional systems under varying spin–orbit and Rabi couplings, identifying zero-momentum, elongated zero-momentum, stripe, and superstripe phases. The emergence and evolution of these phases are governed by spin-dependent interactions and Rabi coupling, with quantum phase transitions characterized through spin-density distributions, miscibility, and condensate size. To uncover the microscopic origin of phase stability and dynamics, we investigate the collective excitation spectrum using Bogoliubov-de Gennes theory, revealing distinct excitation regimes, including phononlike modes and avoided crossings that drive emergent spatial patterns and phase fragmentation, as confirmed by numerical simulations of the coupled Gross–Pitaevskii mean-field equations. We further show how antiferromagnetic interactions qualitatively modify the excitation spectrum, leading to enhanced mode coupling and complex dynamical behavior leading to the appearance of the superstripe phases for small Rabi couplings. Extending the study to quasi-two-dimensional Rashba-coupled systems, we demonstrate the emergence of supersolid-like phases accompanied by roton–maxon–phonon excitations, whose softening gives rise to pattern formation and condensate fragmentation.