Toward Topological Quantum Computing: Skyrmions in a Half-Filled Second Landau Level

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In the context of fractional quantum Hall effect, skyrmions are topological excitations of a two-dimensional incompressible electron liquid, carrying a single (fractional) quantum of electric charge and massive spin. A known example is the Laughlin $\nu = 1/3$ state in which the skyrmions have been both demonstrated experimentally and understood via its mapping onto a completely filled Landau level of composite fermions. Spin dynamics of the incompressible liquids in the Landau level, including the most prominent $\nu = 5/2$ state, are less explored. Adiabatic connection of the polarized phase to an intriguing Moore-Read "pfaffian" wave function with nonabelian quasiparticles has been convincingly demonstrated only recently. On the other hand, it is still not generally accepted if the ground state remains polarized unaided by the Zeeman spin splitting.

In this lecture we will present our recent results on the spin excitations of the $\nu = 5/2$ state. Exact diagonalization studies for up to 12 electrons with spin (matrix dimensions exceeding 10^9) reveal rotationally invariant unpolarized states at flux (i.e., Landau level degeneracy) around the Moore-Read ground state. These states exhibit spin textures, which we identify, based on the analysis of their charge and spin, pair an triplet correlation functions, as the positive and negative skyrmion excitations of the Moore-Read state (or of its particle-hole conjugate at the same filling factor). We devise a method to construct trial skyrmion wave functions for arbitrary, correlated, polarized many-body states, and obtain significant overlaps with the numerical skyrmion states from the exact diagonalization. An interesting aspect of the $\nu = 5/2$ state is that its skyrmions carry twice the charge of an elementary spinless quasiparticle. As the spin polarization at this filling factor is tuned from full to none, we observe a transition of the excitation spectrum that can be interpreted as binding of a pair of like-charged quasiparticles into a single skyrmion. We show that skyrmion states may be energetically competitive with the quasiparticles at low Zeeman splittings. Disorder and high quasiparticle density are also discussed as further mechanisms for depolarization.