Realizing Non-Abelian Anyons

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Anyons are quasiparticles, unique to two-dimensional systems, which obey fractional exchange statistics. Non-Abelian versions of these anyons are particularly sought after. Manipulation of the quantum ground state by exchanging - or 'braiding' - non-Abelian anyons can be used to perform quantum computations. Crucially, information encoded using this scheme is immune to local perturbations and thus protected from quantum decoherence, overcoming a major barrier to achieving a scalable and useful quantum computer. A leading platform for exploring anyonic physics arises from the fractional quantum Hall effect (FQHE) in a two-dimensional electron gas under the application of high magnetic fields and at low temperature. In twisted $MoTe_2$ bilayer, we recently discovered a high-temperature fractional quantum anomalous Hall effect (FQAHE), i.e., a lattice analog of the FQHE occurring at zero magnetic field.

Building on this breakthrough, we will create, investigate, and manipulate non-Abelian anyons towards scalable quantum computers by using $MoTe_2$ moiré superlattices. We will engineer robust FCI states to explore non-Abelian anyons, establish their fundamental properties, and braid zero-field non-Abelian anyons. Our approach will exploit the unprecedented tunablity of moiré quantum materials to control the energy scale, symmetry, and topology of the many-body ground states - directly addressing the DoD's mission of tailoring material properties for the creation and understanding of interacting topological phases. The proposed work would also offer a platform to train the next generation of scientists and engineers in uncharged scientific territory. The success of this Vannevar Bush Faculty Fellowship program would achieve a new paradigm in the research of these long-sought quasiparticles with fractional statistics. Ultimately, the realization of non-Abelian anyons and their braiding would not only fulfill a scientific dream, but also revolutionize quantum technologies via anyon-based qubits for universal fault tolerant quantum computation, a capability crucial for secure and efficient information processing in defense applications.