From Two-Dimensional Materials to Moiré Superlattices

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Two-dimensional (2D) materials have provided a new platform for exploring quantum phenomena in solids. Graphene, with its massless Dirac electrons, is a prime example of how reduced dimensionality can give rise to distinctive electronic properties. The family of 2D materials has since expanded to include transition-metal dichalcogenides (TMDs) and many other atomically thin crystals.

A remarkable feature of 2D materials is that they can be stacked and twisted almost freely. A small relative twist generates a long-period moiré pattern, introducing a new length scale far beyond the atomic lattice. Moiré superlattices can dramatically reconstruct electronic bands and provide a highly tunable platform for correlated and topological phenomena. Examples include flat-band superconductivity in twisted bilayer graphene and Chern bands hosting integer and fractional quantum anomalous Hall states in twisted TMDs.

The possibilities extend far beyond conventional twisted bilayers. Moiré physics is rapidly expanding in diverse directions, from new correlated and topological electronic phases to excitonic and other bosonic states, and to novel collective phenomena involving magnetism, ferroelectricity, and lattice degrees of freedom. At the same time, the increasing freedom of structural design enables us to control dimensionality and periodicity, realize quasiperiodic systems and complex multilayer structures, and explore unconventional topology related to higher-dimensional physics.

In this talk, I will give a broad overview of the evolution from 2D materials to moiré superlattices, highlighting how the freedom to stack and twist atomically thin crystals is transforming our ability to design quantum matter. In the future, the virtually unlimited ways of assembling atomic layers, together with new design principles based on moiré patterns and twist angles, may allow us to create spatial structures beyond those possible in conventional crystals, opening the way to new quantum phases, collective phenomena, dimensionality, and topology.