Engineering Topological Flat Bands in Moiré Quantum Materials: From Symmetry-Enforced Topology to Ideal Quantum Geometry

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Topological flat bands in moiré materials provide a promising platform for realizing correlation-driven topological phases, including fractional Chern insulators and unconventional superconductivity. However, in the existing moiré systems, the topology of the minibands depends sensitively on twist angle, the form of moiré potential or interlayer tunneling, and other material-specific parameters. In this talk, I will discuss two complementary strategies for engineering topological flat bands whose topology is instead controlled by the underlying atomic effective model and is therefore insensitive to twist angle or the detailed form of the moiré potential. First, I will show that a $J_z = \pm 3/2$ Rashba model under a moiré superlattice can realize symmetry-enforced moiré topology, where the low-energy minibands are guaranteed to be either topological insulators or topological semimetals, independent of the detailed form of the moiré potential. Second, I will discuss moiré heterostructures with type-II band alignment, where moiré-localized states hybridize with itinerant bands to form a topological heavy-fermion model. This mechanism provides a tunable route to ideal topological flat bands whose quantum geometry satisfies the ideal trace condition and can support fractional Chern insulating phases. Together, these results establish a topological-quantum-chemistry framework for moiré materials, in which atomic symmetry representations and their induced moiré band representations provide robust design principles for engineering topological flat bands without relying on twist-angle fine tuning.

References

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