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Séminaire AXE 1 - Sciences et Matériaux Quantiques

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Orbital Magnetism and Superlattice Engineering in Monolayer Graphene

Graphene encapsulated in hexagonal boron nitride (BN) provides a versatile platform for exploring how engineered superlattice potentials reshape Dirac-fermion physics. In this talk, I will discuss three studies tracing this evolution from pristine graphene to single- and double-moiré systems. First, in unaligned graphene, highly sensitive giant-magnetoresistance (GMR) magnetometry reveals the long-predicted divergent orbital diamagnetism at the Dirac point, providing a direct signature of the π Berry phase associated with graphene's Dirac-point topology. Second, aligning graphene with a single BN layer introduces a moiré superlattice and satellite Dirac points. Magnetization measurements reveal diamagnetic peaks at these points, together with orbital paramagnetic singularities at saddle points of the moiré minibands, providing experimental evidence for the predicted orbital response near saddle points. Finally, using a different experimental approach, encapsulated graphene with dynamical control of one BN crystal allows for the creation and control of a double-moiré system. Varying the relative angular alignment allows us to map the evolution of its electronic response and explore the interplay between the two superlattices. We identify features associated both with well-defined periodic potentials and with competing incommensurate potentials that give rise to quasi-periodic structures and quasi-Brillouin zones. The quasi-Brillouin zones identified in this regime are characterized by integer gap labels that are theoretically related to second Chern numbers. This connection opens perspectives for exploring higher-dimensional topology associated with the four-dimensional quantum Hall effect in tunable two-dimensional heterostructures. These results demonstrate how orbital magnetometry probes emergent electronic structures, while dynamically tunable multi-moiré heterostructures provide a route to engineering quasi-periodic systems. Together, these approaches open perspectives for probing and engineering electronic topology in van der Waals heterostructures.