Visualizing Complex Electronic Phases in Magic Angle Graphene

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The discovery of myriad correlated phases, including superconductivity, in magic-angle twisted bilayer graphene (MATBG) has cemented it as a powerful platform to study electronic correlations. Thus far, our understanding of these correlated phases has been poor largely due to the lack of microscopic information on them. In this talk, I will present how we use scanning tunnelling microscopy (STM) to visualize the electronic wavefunctions of MATBG. Direct, real-space imaging of correlated phases including correlated insulators, pseudogap phases, and superconducting phases immediately shows a $\sqrt{3} \times \sqrt{3}$ super-periodicity on the graphene atomic lattice that has a complex spatial dependence on the moiré scale. To understand this complex spatial dependence, we introduce a symmetry-based analysis using a set of complex-valued order parameters that describe the local symmetries of the electronic-wavefunctions. Visualizing these order parameters on the moiré scale reveals intricate textures that distinguish the various correlated phases. For the correlated insulators, we compare these textures with those expected for proposed theoretical ground states and find that for samples with typical values of heterostrain, the textures closely match those of the proposed incommensurate Kekulé spiral order. In ultralow-strain samples, our data have local symmetries that more closely match those of the time-reversal symmetric intervalley coherent phase. Furthermore, the superconducting and pseudogap phases show strong signatures of intervalley coherence and can be clearly distinguished from the correlated insulators with the complex-valued order parameters.

[1] Nuckolls, K.P., **Lee, R.L.**, Oh, M. et al. Quantum textures of the many-body wavefunctions in magic-angle graphene. Nature 620, 525–532 (2023). https://doi.org/10.1038/s41586-023-06226-x