Imaging local quantum oscillations in strongly correlated moiré systems

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De Haas-van Alphen quantum oscillations in magnetization have traditionally served as the prime tool for determining the band structure of metals and semiconductors. Utilizing a scanning SQUID-on-tip, we image thermodynamic quantum oscillations with nanoscale spatial resolution and at very low magnetic fields, offering a novel powerful tool for reconstruction of the local band structure with high energy resolution. In Bernal-stacked trilayer graphene with dual gates, we reconstruct the band structure and its controllable evolution with the displacement field with unprecedented precision, and map the naturally occurring strain-induced pseudomagnetic fields as low as 1 mT, corresponding to graphene twisting by 1 millidegree over 1 μm distance [1]. In Bernal bilayer graphene aligned to hBN, we reveal complex band structure with narrow moiré bands and multiple overlapping Fermi surfaces separated by very small momentum gaps. In addition to conventional oscillations obeying Onsager quantization, pronounced quantum oscillations are found to arise from particle-hole superposition states induced by coherent magnetic breakdown [2]. In twisted trilayer graphene, we observe doping-dependent renormalization of the single-particle band structure by Coulomb interactions, greatly increasing the bandwidth of the flat bands and leading to symmetry breaking at half filling. On approaching charge neutrality, we find the ground state to be a nematic semimetal in which the flat-band Dirac cones migrate towards the mini-Brillouin zone center due to exchange interactions, spontaneously breaking the C_3 rotational symmetry [3].

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[2] M. Bocarsly, M. Uzan, I. Roy, S. Grover, J. Xiao, Z. Dong, M. Labendik, A. Uri, M. E. Huber, Y. Myasoedov, K. Watanabe, T. Taniguchi, B. Yan, L. S. Levitov, and E. Zeldov, "De Haas–van Alphen spectroscopy and magnetic breakdown in moiré graphene", *Science* **383**, 42 (2024).

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