Mesoscopic Magnetic Imaging

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Electrons are seemingly simple particles with charge $e$ and spin $\frac{1}{2}$. But, when they live in materials whose composition, structure, and even dimensionality can be carefully designed, they display various complex, emergent states of matter. These states have tremendous potential to be useful as well as interesting, but they can be theoretically difficult to describe and predict.

Electrons create magnetic fields, so the emergent states in these electronic quantum materials must have magnetic signatures. Although distinctive, interesting, and informative, these signatures are hard to measure. When we study finicky new devices, or survey many samples of a new class of materials, we need ultra-sensitive instruments that also work reliably, experiment after experiment. I will briefly compare and contrast the current slate of candidate probes, before concentrating on the current and next generations of Superconducting QUantum Interference Devices (SQUIDs), which have the sensitivity and speed along with the reliability we need to advance materials physics.

These scanning SQUIDs allow us to sensitively, yet non-invasively, watch the electrons on mesoscopic length scales. I will give examples chosen from chiral edge currents in topological superconductors, persistent currents in normal metals, fluctuation superconductivity, the impact of structure on conductivity and superconductivity, trace magnetism in complex oxides, and edge currents in topological insulators.