Ask the Locals: Investigations of Local Atomic and Magnetic Structure in Complex Materials

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The sheer number of interacting quantum particles in solids can lead to fascinating properties that are completely unanticipated by the behavior of individual particles. Understanding this emergent complexity often requires a detailed investigation of the various types of order in the structure of the material, such as the ordered arrangement of atoms or magnetic moments. In many of the most interesting materials, the *local* structure over a few interatomic spacings may differ in important ways from the *average* structure over longer length scales, and these differences can have a crucial influence on macroscopic properties. Careful study of the local structure is therefore necessary. Here, I will present three short stories highlighting the richness and importance of local atomic and magnetic structure in topical condensed matter systems studied with beams of x-rays, neutrons, and muons. First, I will describe the mysterious symmetry-breaking phase in iron-based superconductors known as the nematic phase, along with our discovery that the local structure is characterized by ubiquitous nematic fluctuations in a large region of parameter space. Next, I will introduce geometrically frustrated magnets and showcase our use of a novel analysis technique to determine the short-range magnetic correlations in a new class of frustrated magnets. Finally, time permitting, I will discuss quantum phase transitions and Mott insulators, demonstrating the existence of substantial phase separation at the metal-insulator boundary that indicates a first-order quantum phase transition. Together, these stories teach us that to understand globally, we must first look locally.