Nanoscale Intermittency and Emergence in Complex Materials

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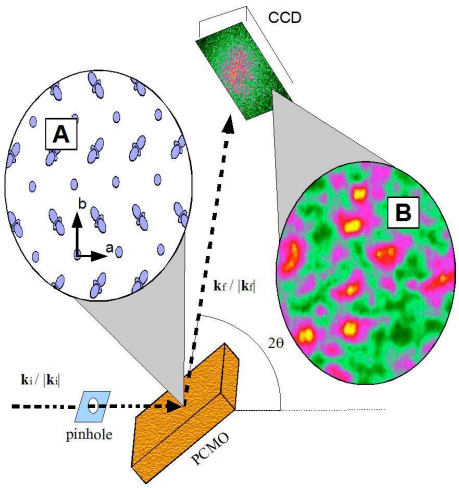
Intermittent microscopic behaviors appear to play a key role in diverse emergent phenomena, including earthquakes,[1] molecular switches,[2, 3] polymer melts,[4] colloidal suspensions,[5] magnetic Barkhausen cascades,[6] and 'blinking' in virtually all single-center fluorophores.[7, 8] Many such intermittent systems exhibit self-organized criticality, where power law behaviors and the absence of a particular length or time scales are key features. Ensemble dynamics of such systems often exhibit complex behaviors, e.g., stretched exponential kinetics and violation of the fluctuation-dissipation theorem, though this connection is rarely well understood.

Given their high sensitivity to local environment, many nanoscale devices and nanostructured materials are expected to exhibit intermittent behaviors and complex ensemble dynamics. For example, fluctuations in the environment are a commonly proposed ingredient in understanding the intermittency of single-center fluorophores.[7, 8] A nanostructured material – the microphase separated domain structure in a manganite oxide, for example - is itself a complex environment, and intermittent domain percolation is evidently an important ingredient in colossal magnetoresistance.[9-12] The ability to control microscopic intermittency will in turn afford the ability to control complex and useful macroscopic behaviors.



A prerequisite to controlling complexity is the ability to measure microscopic intermittency and to correlate it with macroscopic properties. The power law behaviors mentioned above suggest that this will require probing phenomena over a broad range of both length *and* time scale. Coherent hard and soft x-ray beams offer particular advantages in this regard. The figure on the left shows schematically how the internal complexity, in this case of domains in an orbital-ordered phase in $Pr_{0.5}Ca_{0.5}MnO_3$, is projected into a speckle-diffraction pattern that can in principle be analyzed to image the

domains on the scale of a few nanometers through several microns, or to measure the dynamics of the domains on a time scale that is limited by signal and apparatus stability.

I will show recent examples of complexity in magnetic systems probed with coherent, resonant soft x-ray scattering, including 1) stretched exponential decay of magnetic fluctuations near a spin-reorientation transition in a Au:Co:Au heterostructure, 2) the spatial scale of microscopic memory in exchange biased CoPd:IrMn multilayers probed with soft x-ray speckle metrology, and 3) orbital domain fluctuations in $Pr_{0.5}Ca_{0.5}MnO_3$.

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