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Title: Random walks on complex networks: quenched disorder, fluctuations, and universality

Abstract: Universality of critical phenomena lies at the core of statistical physics, yet our understanding is mostly limited to homogeneous systems. In this talk, I will discuss progress in extending the notion of universality to complex networks, an inhomogeneous system whose random connectivity acts as a source of quenched disorder. I will consider a complex network where links are drawn from a Bernoulli distribution. Any two nodes are connected with a probability that follows a power-law based on the distance between them. These links play a dual role: they facilitate long-range (superdiffusive) transport and also introduce correlated disorder. This situation thus lies beyond the conventional Harris and Weinrib–Halperin frameworks for disordered systems, where disorder perturbs a pre-existing clean theory.

To probe universality, I consider a self-avoiding walk (classical transport) on the network. Large-scale Monte Carlo simulations and Gaussian field theory demonstrate that the long-range kinetic operator dominates at large scales, restoring the clean superdiffusive Lévy universality class. In contrast, for single-particle quantum transport, the same random links generate quantum-chaotic level statistics and drive a localization transition. This cannot be captured by Gaussian field theory, signalling that higher-order disorder statistics become relevant. Together, these results suggest that network disorder in the form of random links constitutes a distinct class of disorder that can give rise to a new universality class.