From Many Particles to Kinetic Equations: A Hierarchical Route to Plasma Models

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Abstract: Many models in plasma physics — including the Vlasov–Poisson, Boltzmann, and Landau equations — arise as effective descriptions of large systems of interacting particles. A fundamental mathematical problem is to understand how these kinetic partial differential equations emerge from deterministic many-body dynamics in appropriate scaling limits, and to determine the time scales over which such approximations remain valid.

In this talk, I will describe a hierarchical route from particle mechanics to kinetic equations. Starting from the Liouville equation and the BBGKY hierarchy, I contrast two derivation paradigms: the empirical measure approach, which captures mean-field behavior through law-of-large-numbers arguments, and the hierarchy approach, which directly tracks the evolution of correlations. I focus on the hierarchy framework, where recent advances allow one to rigorously derive Boltzmann-type equations beyond the classical short-time regime of Lanford's theorem and to quantify propagation of chaos for longer times.

I then discuss weak-coupling limits leading to the Landau equation, emphasizing the transition from binary-collision models to grazing-collision regimes relevant for Coulomb plasmas. Finally, I highlight the Hamiltonian structure underlying the Vlasov equation and explain how hierarchical methods naturally arise even in this Hamiltonian setting.

Speaker Biography: Joseph K. Miller (Joe) is a Szegő Assistant Professor in the Department of Mathematics at Stanford University. He received his B.S. in Mathematics from UCLA (2018) and completed his Ph.D. in Mathematics at The University of Texas at Austin in 2024. He joined Stanford in 2024 and recently returned from participating in the Fall 2025 semester program in Kinetic Theory at the Simons Laufer Mathematical Sciences Institute (SLMath, formerly MSRI).

Miller is a mathematical analyst specializing in partial differential equations. His research focuses on the rigorous derivation of effective nonlinear PDEs from many-body dynamical systems, with particular emphasis on models arising in non-equilibrium statistical physics. His work explores hierarchical and measure-theoretic methods for connecting microscopic particle dynamics to kinetic and macroscopic descriptions. He is also interested in applying these techniques to problems in economics and computer science.