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Nonequilibrium Dynamics of Ultracold Neutral Plasmas[1]

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Since their first creation by photoionization of laser-cooled neutral atoms, ultracold neutral plasmas (UNPs) are proving to be interesting dynamical systems on the border between atomic and plasma physics. The low initial temperatures suggest these systems to be in a strongly coupled state, where the electrostatic potential energy greatly exceeds the kinetic energy of the produced charges. Hence, they potentially allow to observe fundamental effects such as Coulomb crystallization in a two-component plasma or to study atomic collision processes under conditions, otherwise realized mostly in exotic astrophysical environments. I will present a numerical approach, which is demonstrated to yield an accurate description of recent experiments and to provide deeper insights into the complex system dynamics. Strong ion correlations are proven to profoundly affect the plasma evolution, leading, e.g., to a wave-like temperature dynamics as the system heats up intrinsically. It is found that common kinetic descriptions break down in this exotic regime, resulting in an unusual relaxation behavior towards thermodynamic equilibrium – and even away from it. To get around the drawback of intrinsic plasma heating, I will discuss a promising perspective for controlling the degree of correlations in UNPs by laser-cooling the ions as the plasma expands. It turns out that additional cooling strongly modifies the plasma dynamics and allows for the realization of different phases. In fact, even Coulomb crystallization is shown to be achievable under realistic experimental conditions. Interestingly, the observed crystallization is found to proceed substantially different than the dynamical crystallization observed in ion traps. In this context, I will also discuss perspectives for trapping UNPs, including magnetic effects on several aspects of the system dynamics.

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