English summary

The thesis of Tobias M. Wintermantel with the title “Complex systems dynamics in laser excited ensembles of Rydberg atoms” presents experimental and theoretical findings showing that an ultracold gas under laser excitation to Rydberg states can provide a tunable platform for studying the interesting complex dynamics emerging in driven-dissipative systems. The three main finding supporting this connection are:
(i) The discovery of self-organized criticality (SOC) in our Rydberg system under facilitated excitation via three signatures: First we observe self-organization of the density to a stationary state. Second, we find scale invariant behavior in the bulk observable density. And third, we measure a critical response of the system in terms of power-law distributed Rydberg excitation avalanches. In further studies, we unravel an intrinsic mechanism in the system which stabilizes the SOC state via atom motion. Furthermore, a controlled stabilization mechanism via tuning of the laser driving is presented. These results can help answer the question of why scale invariant behavior is so prevalent in nature.
(ii) A connection between the power-law growth of the Rydberg excitation number and epidemic spreading is revealed. Motivated by this, an epidemic susceptible-infected-susceptible network model is developed which can efficiently model the collective excitation dynamics in the system. This model points to the importance of heterogeneity in the emergent Rydberg network and to associated Griffiths effects, which provide an explanation for the observed non-universal power laws.
(iii) A novel theoretical proposal to implement quantum cellular automata via multi-frequency Rydberg laser excitation in atomic arrays provides a natural framework to study the relation between microscopic rules and resulting global dynamics. A powerful application is the state preparation of entangled states in the steady-state dynamics of the quantum cellular automata system with applications in quantum metrology and computing.

Reference: Tobias M. Wintermantel, “Complex systems dynamics in laser excited ensembles of Rydberg atoms”, Dissertation, Ruprecht-Karls-Universität Heidelberg and Université de Strasbourg, 2021